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Incorporating Physical, Social, and Institutional Changes in Water Resources Planning and Management

Lessons from a Review of Case Studies

Larry W. Canter, Manroop K. Chawla, and Carl Thomas Swor

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Abstract

The US Army Corps of Engineers is increasingly moving toward a watershed or systems-based approach to water resources management infrastructure. A key component of this holistic approach is understanding the current context of the watershed and the many changes that have shaped the existing system. This report summarizes and compares 31 case studies where causative physical, social, and institutional (PSI) changes were connected to consequential PSI changes associated with water resources planning and management. Consequential changes can also occur in runoff, water quality, and riparian and aquatic ecological features. The 31 studied cases were systematically evaluated relative to: causative and consequential PSI changes (environmental effects); use of analytical frameworks and appropriate models, methods, and technologies; and the attention given to mitigation and/or management of the resultant changes. Some general observations and lessons learned were that study features were unique for each case; consequential environmental effects appeared to be logical, based on the causative changes; analytical frameworks provided a relevant structure for studies; and identified methods and technologies were pertinent for addressing both causative and consequential changes. One key lesson derived from the case study reviews was that they provide useful, "real-world" illustrations of the importance of addressing PSI changes in water resources planning and management.

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Preface

This study was conducted for the Headquarters, US Army Corps of Engineers under Project Number 145759, “Incremental Changes over Time in Watershed/System (Theme 1, PDT 6).” The technical monitor was Dr. Kathleen White (CEIWR-GR).

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COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
hectares	1.0 E+04	square meters
miles (US statute)	1,609.347	meters

Abbreviations

Term	Meaning
ABIMO	German abbreviation for a water balance model
ALCES	A Landscape Cumulative Effects Simulator
ANCOVA	analyses of covariance
BAC	best attainable condition
B-IBI	benthic indices of biotic integrity
BJS	Budget Justification Sheet
BMP	best management practice
CEA	cumulative effects assessment
CEAM	cumulative effects assessment and management
CEQ	Council on Environmental Quality
CSO	combined sewer overflows
CSRF	Case Study Review Form
CWA	Clean Water Act
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
EPT	Ephemeroptera, Plecopteria, and Trichoptera
ERA	ecological risk assessment
ESA	Endangered Species Act
FWCA	Fish and Wildlife Coordination Act
GIS	geographic information system
GPS	global positioning system
HC	historical condition
HSI	habitat suitability index
IBI	index of biotic integrity
IWMP	Integrated Watershed Management Plan
IWRRI	Idaho Water Resources Research Institute
LDC	least-disturbed condition
LP&VHPP	Lake Pontchartrain and Vicinity Hurricane Protection Project
LQ	location quotient
MDC	minimally disturbed condition
NEPA	National Environmental Policy Act
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration

Term	Meaning
PATCH	Program to Assist in Tracking Critical Habitat
PCB	Polychlorinated biphenyls
PMH	Project Maximum Hurricane
PSI	physical, social, and institutional
QHEI	Qualitative Habitat Evaluation Index
RC(BI)	reference condition for biological integrity
RFFA	reasonably foreseeable future actions
RIAM	Rapid Impact Assessment Method
SAMP	Special Area Management Plan
SEPM	Spatially Explicit Population Model
SPF	Standard Project Flood
SPH	Standard Project Hurricane
TMDL	total maximum daily loads
UGB	urban growth boundaries
USACE	US Army Corps of Engineers
VEC	valued ecosystem components
WFD	Water Framework Directive
WINOE	Willamette invertebrate observed/expected (index)
WRB	Willamette River Basin
WRDA	Water Resources Development Act
WRI	Willamette Restoration Initiative
WRPA	Water Resource Protection Area
WVLF	Willamette Valley Livability Forum

1 Introduction

1.1 Background

The US Army Corps of Engineers (USACE) is increasingly moving toward a watershed- or systems-based approach to planning, engineering, operating, and maintaining water resources management infrastructure (USACE 2011). A key component of this holistic approach is an understanding of the current context of the watershed and the many changes that have shaped the existing system. This report focuses on a review of 31 case studies where physical, social, and institutional (PSI) changes were addressed in water resources planning. The studies include both USACE and non-USACE examples, taken primarily from peer-reviewed journal articles. The review demonstrates that PSI changes can be and have been addressed in water resources planning. Though the case studies did not routinely use the term "physical, social, and institutional changes" per se, one or more PSI changes (or combinations of changes) were addressed in each of the 31 selected cases. Further, lessons derived from these cases can be utilized by USACE to develop best-practice principles for incorporating an understanding of the types and effects of PSI changes that are important in water resources planning.

This chapter introduces the concept of PSI changes and their associated planning and environmental consequences, summarizes the process used to identify and review the 31 selected case studies, describes six categories of PSI changes derived from the cases, and lays a foundation for the following chapters.

1.2 Concept of physical, social, and institutional changes

In a previous report (Canter, Chawla, and Swor 2011), the phrase "incremental changes" was used to describe periodic or continuing small to large changes over time. These changes can influence hydrologic, geomorphic, ecologic, social, and economic conditions in localized areas—at the watershed level or in a regional river basin context. These changes encompass the numerous modifications to legislation, policies, and regulations that have been implemented (or may be implemented in the future) that can be called institutional changes. Institutional changes have individually and collectively contributed to determining how USACE projects are planned,

evaluated, designed, constructed, operated, and modified at any given point in time. As societal demands change and the nation's priorities evolve, the myriad of laws, policies, and procedures employed in formulating, evaluating, selecting, designing, constructing, and operating USACE projects reflects national values at some point along the continuum of ongoing social changes.

Historic and current changes can reflect the influences of local to regional economic development initiatives on physical processes, including land use changes to accommodate housing and various societal demands of increasing populations. For example, runoff hydrographs can be altered in both timing and magnitude as a result of urbanization. New laws and resultant USACE policies and regulations can also initiate changes in environmental requirements and emphases (e.g., incorporation of resource sustainability), as well as funding requirements for project sponsorship (e.g., local sponsors and cost-sharing). Design changes may also occur as a result of new policies reflecting changes in historical practices (e.g., design flood and the introduction of risk considerations in both flood damage reduction and costs). Collectively, these types of changes can be referred to as physical changes.

Historic PSI changes and how they shape the context of a watershed must be evaluated when planning new project designs and operations. Unanticipated changes in local, regional, or institutional contexts often occur during the life cycle of projects, and such occurrences may create the need for design or operational modifications to projects as a means of maintaining or enhancing their continued functionality. Accordingly, project designs and operational plans should be seen as dynamic endeavors and periodically evaluated and modified as appropriate. This approach combines situational awareness with an adaptive management strategy.

The likelihood of future PSI changes should be anticipated and appropriately considered in planning and designing new projects as well as in potential modifications to existing projects. Such future changes may be influenced by foreseeable economic development and land-use changes, new or revised legislation and policies, and/or the collective effects of multiple changes in hydrologic, ecologic, economic, and other conditions resulting from actions by other public agencies and private interests. Further, new themes in water resources project planning and operation can contribute both to PSI changes and improved project management.

Examples of new themes include issuance of the Chief of Engineers' Environmental Operating Principles, adaptive management, consideration of resource sustainability, and incorporation of climate preparedness and resilience.

There are three key observations to the concept of PSI changes that are important in water resources management.

1. The concept can be applied to all USACE mission areas.
2. The planning process can be improved in a given watershed or subwatershed by recognizing and understanding historic, current, and future changes in the identified study area. This action may require retrospective analyses to identify historic and current changes, and prospective analyses to designate potential future changes.
3. Multiple projects, development, and policy decisions can be initiators of PSI changes.

1.3 Process used to identify and review the case studies

The process used to identify potentially useful case studies emphasized peer-reviewed journal articles, although broader consideration encompassed several conference papers and specific research reports. A total of 580 documents (peer-reviewed journal articles, conference papers, research reports, and books) were initially identified. Based on their abstracts, the documents were then categorized into four groups of potentially relevant case studies: (1) analytical frameworks for planning studies of PSI changes; (2) relevant method and technologies (tools) which could be used in addressing PSI changes related to water resources planning and management; and (3) useful background reading related to PSI changes and their environmental consequences.

A total of 43 documents related to potentially relevant case studies were identified for the first group, which were then subjected to reviews by two or all three authors of this report. A Case Study Review Form (Appendix A) with a common set of review criteria (questions) was developed to support the reviews. Each primary reviewer was asked to describe the extent to which each of the following questions (or topics) was discussed in the specific reference:

- Which PSI changes are addressed?

- Does the study help illustrate PSI changes or consideration of these changes in water resources planning?
- Does the study provide an analytical framework for evaluating PSI changes?
- Is the information on methods transferable to other efforts or studies?
- Is there discussion of mitigation and/or management of PSI changes?
- Does the study discuss use of any tool? (e.g., geographic information systems [GIS], indicators, scenarios, sustainability analysis, conceptual models, etc.)
- Other factors?

This review process yielded 31 case study “gems”—studies that demonstrated useful information on PSI changes which are addressed in Chapters 3 through 8 of this report. Again, it should be noted that the words “PSI” or “physical, social, and institutional changes” were not necessarily used in the 31 selected case studies.

1.4 Categories of physical, social, and institutional changes in the selected case studies

Each of the 31 cases was then categorized by the types of PSI changes included. Six categories were identified based on reviews of the studies. These categories and their relevance to water resources planning within USACE are outlined below.

1. *Institutional changes associated with water resources and environmental legislation and policies*. These legislative and policy changes have been incorporated by USACE over many decades. However, the unintended consequences of such changes on planning, design, construction, and operation of specific projects (or even broader plans) have not always been recognized in advance. This previous lack of recognition suggests that attention should be given to legislative and policy analyses prior to their automatic inclusion in water resources planning.
2. *Physical changes associated with land use changes in urbanizing watersheds*. Increasing awareness of the effects of urbanization on surface water runoff, groundwater recharge, flood flows, and water quality has long been recognized by USACE. This issue is being addressed in relation to historical conditions and current changes, and via the use of scenarios of alternative futures.

3. *Physical changes associated with land use changes and development projects in watersheds*. Increasing awareness of the effects of these types of physical changes is also being given in the watershed-based planning being embraced by USACE and other federal water agencies. Finally, the importance of all PSI changes is also receiving attention in watershed planning.
4. *PSI changes associated with land use and related policy changes in river basins*. This holistic river-basin perspective is being utilized in USACE strategic planning studies. Beyond concerns related to runoff, recharge, flood flows, and water quality, new opportunities are occurring for giving attention to sustainable water management, environmental flows for maintaining aquatic ecosystems, and environmental features in project design and operation.
5. *PSI changes associated with land use and related policy changes in river basins*. For example, a comprehensive study in the Willamette River Basin in Oregon involved: numerous advisory groups; three alternative future scenarios; and attention to effects on agricultural land uses, wildlife, water needs and environmental flows, and fish and aquatic invertebrate communities (Baker et al. 2004; Dole and Niemi 2004; Schumaker et al. 2004). USACE has also been the lead on comprehensive studies in river basins; one example is the Ohio River Mainstem Study (Canter and Rieger 2005; USACE 2006).
6. *PSI changes associated with climate variability and change*. Examples of such changes include sea-level change in coastal areas and changes in air temperature, precipitation, runoff, and drought. USACE and other federal water resources agencies are working together to assemble locational and time-related information on such consequences, and on mitigation and adaptation strategies (e.g., Brekke et al. 2009).

1.5 Structure of report

This report has been structured with nine chapters and two appendices. Chapter 2 addresses a seminal event that prompted this study of PSI changes—the consequences of Hurricane Katrina during 2005 in the New Orleans area and related studies and analyses, particularly with regard to the design, funding, and operational features of the Lake Pontchartrain and Vicinity Hurricane Protection Project (LP&VHPP). This event will be summarized in relation to legislative, policy, and land use changes occurring over multiple decades.

Chapters 3 through 8 involve the review of the 31 selected case studies which addressed PSI changes; the large majority of these cases did not involve USACE. Common topics are addressed for each of the 31 cases including: features of PSI changes; environmental effects studied; analytical frameworks used; methods and technologies which form the basis for the analyses; and project mitigation and broader management measures which were noted for addressing undesirable PSI changes. Lessons learned in relation to these topics within each category are also highlighted.

Chapter 9 contains a summary of this report. A reference list follows Chapter 9 with a composite listing of the references mentioned throughout this report.

Appendix A contains the Case Study Review Form which was used to summarize each case study. The summaries are included, by topic, within Chapters 3 through 8.

2 Situational Context for Physical, Social, and Institutional Changes: Hurricane Katrina in 2005

2.1 Introduction

This chapter contains a brief review of a variety of PSI changes that occurred over a five-decade period associated with hurricane protection planning and implementation for the Greater New Orleans area in Louisiana. On 29 August 2005, Hurricane Katrina's storm surge overwhelmed many of the levees and floodwalls for greater New Orleans that were designed and constructed by USACE and were collectively known as the Lake Pontchartrain and Vicinity Hurricane Protection Project (LP&VHPP). The result was a human tragedy—more than 1,600 people killed or missing and presumed dead, with over 1,250 confirmed deaths in Louisiana alone. In economic terms, the flooding from Katrina represents the costliest natural disaster to date in US history. Direct flood damages to residential, non-residential, and public properties and infrastructure in greater New Orleans approached $28 billion, with further indirect economic effects and long-lasting socioeconomic disruption to the region.

In the immediate aftermath of the tragedy, the Secretary of Defense directed on August 29, 2005, that the US Army enlist the National Academy of Sciences and National Research Council to conduct a thorough review of the engineering aspects of the performance of the levees and floodwalls that were in place in New Orleans. Several resultant reports are now available (Committee on New Orleans Regional Hurricane Protection Projects 2006a, 2006b, 2006c, 2008, and 2009). Among other actions, these analyses recommended, that USACE improve its process to incorporate information about new and changing conditions. This recommendation, in turn, led to the current project to address PSI changes in planning requirements, design standards, construction practices, operation of, and cost-sharing for any major hurricane protection project.

In addition, USACE concurrently commissioned a study of the decision chronology of the LP&VHPP over the 50-year period from 1955 to 2005. The results of this study by two independent university researchers are the focal point of this chapter (Woolley and Shabman 2008). Three examples

of their findings are included in this section. First, a subsection related to decision timelines and decision makers is presented. This is followed by a chronological review of project design parameters and benchmark elevations. The third subsection highlights reflections by the authors on historic issues as well as future needs in local water resources planning and management.

2.2 Decision timelines and decision makers

Highlights of the chronology's findings as related to decision timelines, funding, and policies are noted below; some significant congressional, judicial, and USACE Headquarters decisions are included from Woolley and Shabman 2008 (p. ES-9).

- 1955 – Congress authorizes USACE to conduct hurricane protection studies.
- 1959 – Congress establishes federal (70%) and local (30%) cost sharing for hurricane protection projects – this factor influenced the alternatives examined and subsequent decision making.
- 1966 – Congress authorizes the LP&VHPP Barrier Plan.
- 1976 – The project's Environmental Impact Statement (EIS) was challenged in a federal court lawsuit; the Court imposed an injunction against USACE.
- 1979 – The federal injunction was lifted for all parts of the project other than the barrier complexes.
- 1981 – A preliminary planning document indicated that the alternative entitled the High Level Plan is less costly to complete and less damaging to the environment.
- 1985 – The LP&VHPP Reevaluation Study recommends the High Level Plan, and it is approved under the discretionary authority of the Chief of Engineers.
- 1991 –Congress directs USACE to favorably consider another alternative, known as the Parallel Protection Plan, for all of the outfall canals in New Orleans – this topic was incorporated in the Water Resources Development Act (WRDA) of 1990
- 1992 –Congress directs USACE to implement the Parallel Protection Plan and funded the work at the 70% federal cost-share level, and this information was included in the WRDA of 1992.

The above chronology encompasses a 38-year period during which cost-sharing for funding was initiated. One consequence of this change from

100% federal sponsorship is associated with challenges arising during consensus-building across multiple stakeholder groups. Local sponsors are typically focused on least-cost solutions. Another change was associated with the challenge of meeting compliance requirements of the National Environmental Policy Act (NEPA). Debates often occurred in relation to detrimental impacts on environmental and natural resources within Lake Pontchartrain versus the inclusion of designs to address various categories of hurricanes. Finally, an interesting feature of this chronology was congressional-level advocacy for the Parallel Protection Plan over the USACE recommendation for the High Level Plan. As can be inferred from this chronology, numerous seemingly small changes occurred over the 38-year period. The accumulated importance of these changes was probably not adequately recognized and evaluated in the long-term planning and design process.

2.3 Design parameters and benchmarks

Examples of chronological project-related decisions associated with the design parameters and benchmarks for the LP&VHPP are listed below (Woolley and Shabman 2008, ES-13).

- 1960 – National Hurricane Research Project (Report 33) established the Standard Project Hurricane (SPH) for the area and compared SPH with the Standard Project Flood (SPF).
- 1963 – An Interim Survey Report for the LP&VHPP established the SPH as the design hurricane for the Greater New Orleans area (this SPH wind speed and central pressure remained unchanged over the design period for the hurricane protection project).
- 1966 – The LP&VHPP was initially authorized by Congress (a post-authorization change added 1–2 ft to all structure designs, based on the wind fields experienced during Hurricane Betsy's impact at New Orleans in 1965).
- 1969 – Hurricane Camille occurred in the Greater New Orleans area, including the nearby Mississippi Gulf Coast. USACE New Orleans District comparisons indicated that Camille's wind speeds and central pressures were more severe than the earlier-designated Project Maximum Hurricane (PMH) that was intended to represent the meteorological worst-case scenario for the LP&VHHP; however, no design height updates were made for the LP&VHPP.
- 1980 – National Oceanic and Atmospheric Administration (NOAA) Technical Report NWS 23 provided new SPH and PMH parameters for

the Greater New Orleans area; however, they were not incorporated into the design for the LP&VHPP.
- 1985 – A USACE Reevaluation Report provided new SPH parameters; however, the original SPH parameters were still used for design purposes.
- 1986 – The USACE New Orleans District froze the benchmark elevations of previously constructed works to NGVD 29 (National Geodetic Vertical Datum 29 feet). This datum was related to one established for the area in 1929. This decision did not take into account long-term land subsidence in the Greater New Orleans area.
- 1993 – The USACE Coastal Engineering Research Center developed an Advanced Circulation Model for the evaluation of storm surges; however, the model findings were not used to revise design features of the LP&VHPP. However, it should be recognized that such revisions would have been costly and required additional time for completion.

In addition, several decisions were made on outfall canal designs in relation to their influence on levees in the area. WRDA 1990 and WRDA 1992 both included directions for USACE to implement the Parallel Protection Plans for outfall canals in the area. These plans were largely based on I-type floodwalls. Cost considerations influenced the various designs and their evaluation in regard to protection against certain category levels for hurricanes.

Several PSI changes are incorporated in the above chronology. One example is associated with changes in the SPH for the area. Such changes would be expected as data from more recent hurricanes were explored. However, the SPH used in the initial years of project design was not adjusted to incorporate the new information. For example, land subsidence could certainly be recognized as routinely occurring throughout the Greater New Orleans area. Further, such occurrences were not geographically uniform. Subsidence-related changes were not incorporated in NGVD 29; again, such incorporation would have been time-consuming and expensive. Finally, the potential benefits of using the Advanced Circulation Model were not included in the design process.

2.4 Reflections on New Orleans hurricane protection

Based on their detailed reviews of the above decision chronologies and other information related to the LP&VHPP, the report authors enumerat-

ed the following reflections (Woolley and Shabman 2008, ES-16–ES-18); the quoted material is followed by observations from this report's authors:

- "Concerns about project cost growth, constrained federal and local budgets, delays in project completion, and the possible need for reauthorization if major changes were proposed, help to explain District decisions to construct the project according to original designs and datum benchmarks." This statement infers that PSI changes associated with design factors, as well as maintaining NGVD 29, were not adequately recognized over the multi-decade planning period.
- "There was no USACE organizational process that required and provided funding for a continuing assessment of project performance capability during the post-authorization implementation period." With new information and analytical techniques which became available over the 50-year design and implementation period, the influence of numerous PSI changes could have been evaluated.
- "There is no evidence in the project record indicating that project engineers believed that the decisions made would threaten engineering reliability." This reflection suggests that the various potential influences of PSI changes were not adequately recognized nor evaluated.
- "The only recurring organizational provision for systematically reporting the expected performance capability of the project was the annual Budget Justification Sheet (BJS)." However, the BJSs did not delve into the subject of PSI changes.

Finally, based on their extensive study, the decision chronology authors identified two reflections related to the future (Woolley and Shabman 2008, ES-18–ES-20). First, they noted the importance of sharing knowledge among USACE, all stakeholder groups, and other pertinent federal, state, and local agencies. Their second significant reflection was focused on the need for flexibility and adaptation in project planning, design, and implementation. This reflection will be heightened in importance within study areas which have or will experience multiple types of physical, social, and institutional changes over time. Such changes can increase future uncertainties, hence the need for an adaptive design and management approach.

One specific conclusion of the chronology report was (Woolley and Shabman 2008, 6-20): "As future protection of the Gulf Coast is planned, it must be recognized that the vision set forth in any plan will necessarily

change during implementation in response to new information, changing costs, stakeholder values, and agency missions, policies, and budget priorities." This conclusion strongly infers the need to address both historic, current, and anticipated future PSI changes in water resources planning and management.

3 Institutional Changes Associated with Water Resources and Environmental Legislation and Policies

3.1 Introduction

This chapter summarizes seven case studies related to institutional changes resulting from evolving legislative requirements and policies associated with WRDAs such as NEPA, the Endangered Species Act (ESA), the Clean Water Act (CWA), and the Fish and Wildlife Coordination Act (FWCA). The cases are diverse in their focus, associated institutional changes, and lessons learned.

Section 3.2 presents the case order. In Section 3.3, Subsections 3.3.1–3.3.7 summarize the seven addressed cases by presenting information on each case derived from using the review form in Appendix A. Section 3.4 contains a comparative discussion of the key findings from each case. Finally, several overall lessons are highlighted in Section 3.5.

3.2 Order of case studies

The seven case studies summarized in this chapter are presented in the order listed below.

1. Ex-post reviews (retrospective studies) of water resources projects (Jacobs 2002)
2. Retrospective analyses of institutional capacities to reallocate water (Slaughter and Wiener 2007)
3. Hierarchical framework for evaluating impacts from physical changes in dam operations (Burke et al. 2009)
4. Addressing cumulative effects assessment and management (CEAM) within NEPA compliance for inland navigation (Canter and Rieger 2005)
5. Addressing CEAM within a Canadian river basin (Sullivan 2009)
6. Establishing reference conditions from stream biological assessments (Stoddard et al. 2006)
7. Ecological designs for water resources projects (Herricks and Suen 2006)

A common theme for each of the seven cases was that retrospective studies can be useful for informing changes that are institutionally driven or reflect new requirements for design or operational practices. The first six cases specifically or indirectly referred to monitoring and/or adaptive management. The fourth and fifth cases are related to changes introduced by processes associated with CEAM. Finally, the last two cases relate to scientific issues which can be used in project design, environmental impact studies, or for demonstrating the advantages of ecological features of water resources projects.

3.3 Description of case studies

Following are summary descriptions of each of the seven case studies included in this section.

3.3.1 Ex-post reviews of water resources projects

Jacobs (2002) addressed the policy background and need for ex-post (retrospective) reviews during the operational phases of water resources projects and programs. These retrospective reviews, along with consideration of future needs, were recommended by the National Research Council for adoption by USACE and other federal water agencies (Panel on Methods and Techniques of Project Analysis 2004a). Institutional changes which were enumerated by Jacobs (2002) included evolving societal perspectives regarding single or multiple water resources project purposes. Some changes are responsive to legislative requirements for such project purposes and the addition of new purposes for existing projects. Further, Jacobs noted that changes in agency mandates and missions may result in overlaps with other agency responsibilities. In order to be responsive to these changes, the use of ex-post reviews (retrospective evaluation studies), including monitoring and adaptive management as appropriate, was advocated.

Jacobs (2002) suggested that USACE's current six-step water resources planning process (USACE 2000), plus additional evaluations using concepts from the field of policy sciences, would provide useful analytical frameworks for the noted changes. These frameworks could be used for existing water resources projects as well as those in the planning stage. Two specific methods were proposed for planning and implementing ex-post reviews: (1) monitoring planning and (2) the use of monitoring planning results in a project-specific adaptive management program. Increas-

ing attention is being given to the use of these tools in related environmental impact studies (Canter and Atkinson 2010; Panel on Adaptive Management in Resource Stewardship 2004b). Also, the principles associated with monitoring and adaptive management are readily transferrable to other locations, types of projects, planning efforts, and operational programs.

No specific discussions of mitigation and/or management of change were included (Jacobs 2002). However, such discussions were inferred via emphases on project operational and management changes which could result from an adaptive management program. Finally, useful perspectives were included in support of adopting routine ex-post evaluation studies for existing projects, as well as their inclusion in planning for new projects. Such reviews (studies) should also incorporate evaluation criteria and independent analyses from subject matter experts.

3.3.2 Retrospective analyses of institutional capacities to reallocate water

Slaughter and Wiener (2007) conducted a retrospective study of how differences in water law and perspectives regarding water rights in Idaho and Oregon influenced each state's ability to deal with changes in technology, water use, and water demands; the study included results of court decisions and ESA consultations. Such changes were illustrated through the evolving history of federal investments in support of irrigation. Currently, climate change poses threats to the assumptions underlying many of the West's water systems, specifically the assumption that snow accumulation at high elevations will provide runoff during the hot summer months. Further, it is anticipated that pressures for water transfers will increase over time. Accordingly, institutional capacities were examined for re-allocating water among users and for water uses under stress from multiple sources. For example, climate change threatens to add to those stresses in snowmelt systems by changing the timing of runoff and possibly increasing the severity and duration of drought. Warming is expected to advance the period of peak runoff by 30 days and more over the next quarter- to half-century, thus reducing summer water availability by 30%-50%. A change of that magnitude, even if total precipitation were to rise, would require either changing the allocation of water uses or finding additional storage on some of the Pacific Northwest's major rivers.

This case provides a good comparison of approaches in two states to managing water issues, and the ability of each to accommodate changing technology, demands, legislation, court decisions, etc., while maintaining the sustainability of their water resources. A retrospective analytical framework was used to demonstrate how differences in water law and perspective of water rights in the two states undergirded each state's ability to deal with institutional changes. Examples of methods and technologies used included reference to the Idaho Department of Water Resources toolkit that has a procedure for determining the extent of potential injury and any required mitigation from reallocations. Backing up that policy process was a hydrologic modeling system developed in conjunction with the Idaho Water Resources Research Institute (IWRRI), at the University of Idaho. Conflict resolution techniques were also used in relation to issues involving demand growth, drought, and environmental constraints on water use.

Regarding mitigation or management of institutional changes, this case concluded that private ownership of water rights has been a major positive factor in successful adaptation, by providing the basis for water marketing and by promoting the use of negotiation and markets rather than politics to resolve water conflicts. The environment has been better served where certainty of interests has allowed transferability and reallocation through evolving institutions rather than as the result of a more politicized process where outcomes may be less predictable. Conjunctive management—defined as management of water rights for both surface and groundwater within the same body of law and regulation—was also noted as a positive concept and strategy (Slaughter and Wiener 2007).

To summarize, this case provides a useful example of tracing the ability to deal with institutional changes from the time of original enabling legislation up to current conditions. It also provides a good comparison of how different approaches to water law application have influenced the ability to accommodate changes stemming from a variety of sources and actions.

3.3.3 Hierarchical framework for evaluating impacts from physical changes in dam operations

Water releases from dams or in storage within the associated reservoirs can cause PSI changes. Retrospective studies of the effects of such changes can inform future operational decisions and planning studies for new projects or modifications in existing ones. Burke et al. (2009) conducted such studies for the independent and combined operations of two dams on the

Kootenai River in the northwest areas of the United States (Libby Dam) and Canada (Corra Linn Dam), respectively. Three time periods were also examined: (1) historic period prior to the Corra Linn and Libby Dams (1910–1938), (2) the pre-Libby Dam period (1939–1967), and (3) the post-Libby Dam period (1975–2003).

The effects of operational changes were evaluated in four orders:

- first order — hydrology, water quality, and sediment supply;
- second order — floodplain morphology, channel morphology, hydraulics, and sediment transport;
- third order — floodplain and aquatic vegetation, and invertebrates, fish, birds, and mammals; and
- fourth order — biological feedback.

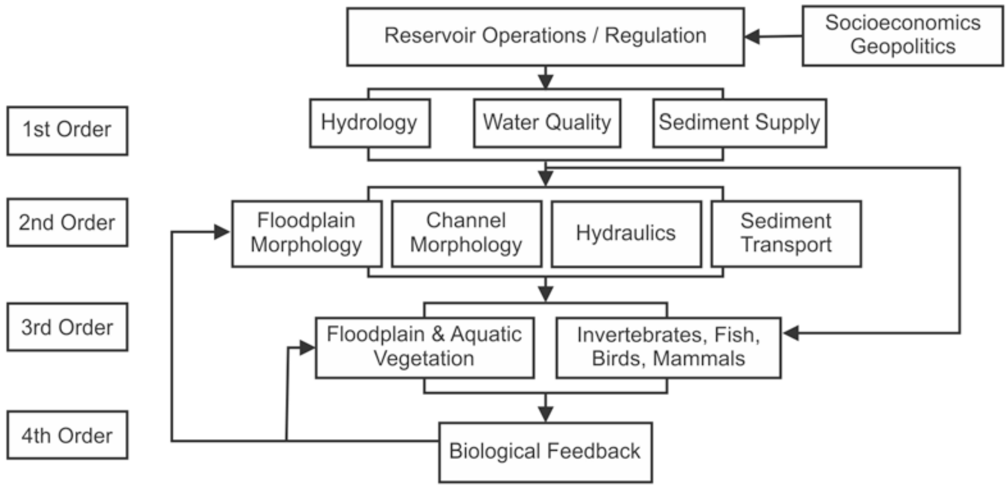
These four orders are indicative of specific indicators for valued ecosystem components (VECs). Assemblage of historic to current monitoring data was required.

An analytical framework was developed to depict the relationships between operations and consequences on the various orders. Figure 1 delineates the conceptual framework (Burke et al. 2009). Further, flow models, indicators, historical monitoring information, and reviews of scientific literature were used as methods or technologies. The methods included flow modeling to determine maximum flow depth, wetted width, daily stage fluctuation, velocity, bed shear stress, unit stream power, and bed mobility. Other tools such as literature reviews and research studies were also used for higher-order effects.

All of this study's methods and their associated principles would be transferable to other operational studies for dams.

Finally, no specific discussion of mitigation and/or management was included. However, monitoring information on the consequences of operational changes could be used in follow-on decision making, which would be an illustration of an adaptive management program.

Figure 1. Hierarchy of physical and biological impacts caused by operational patterns of dams (Burke et al. 2009, S225).



3.3.4 Addressing CEAM within NEPA compliance for inland navigation

NEPA compliance documents are required to address CEAM. While this topic was included in the 1979 NEPA regulations from the Council on Environmental Quality (CEQ), the topic was not given major attention until the 1990s. Further, CEAM includes process-related changes. For example, issues that represent specific changes in NEPA compliance practice are: selecting appropriate VECs; analyzing the contributed effects of multiple past and present actions along with reasonably foreseeable future actions (RFFAs); considering the historic to the future sustainability conditions for the VECs; and incorporating project mitigation and larger area (regional) management of combined cumulative effects on the VECs. In large-scale planning efforts, CEAM studies may be used to address the combined effects of multiple actions including the proposed action and its alternatives.

In a 2005 conference paper, Canter and Rieger described cumulative effects assessment (CEA) or CEAM as the integral component for environmental issues that are related to the timing and introduction of navigation system improvements. Specifically, changes that resulted from modernization of 19 locks and dams on the Ohio River, from modifications in operational patterns involving barge queuing and lock passage, and from experienced and potential land use patterns and developments were evaluated relative to their resultant effects on 12 VECs.

The initial VECs and their subgroups (in parentheses) included:

1. Aquatic ecological resources (water quality and sediment quality, fish, and mussels)
2. Air quality
3. Riparian and floodplain ecological resources (terrestrial habitat, islands, wetlands, soil and geology, and floodplain hydrology)
4. Threatened or endangered or protected species (fish, mussels, mammals, birds, and plants)
5. Aesthetic resources
6. Human health and safety
7. Land use
8. Transportation and traffic
9. Recreational uses of the river
10. Noise
11. Cultural resources
12. Socioeconomic resources

Subsequently, more detailed analyses were related to the six key VECs: water and sediment quality, fish, mussels, riparian or floodplain resources, water-related health and safety, and water-based recreation.

The analytical framework for the CEAM study for the Ohio River Mainstem was based on applying the CEQ's 11-step process (CEQ 1997). Briefly, the 11 steps are indicated below (Canter and Rieger 2005).

- Four steps on scoping:
    - identify cumulative effects issues associated with the proposed action,
    - identify key VECs based on the direct and indirect effects of the project and alternatives,
    - delineate appropriate spatial and temporal boundaries for each VEC, and
    - identify other past, present, and future actions which have or could contribute to VEC-related cumulative effects.
- Three steps describing the affected VECs and their environment:
    - life cycles and carrying capacities
    - current conditions and sustainability for each VEC, and
    - historical reference point and trends conditions and sustainability for each VEC

- Four steps related to determining environmental consequences;
  - establish connections between actions and VECs,
  - determine relative or quantitative contributions of various actions to the cumulative effects on specific VECs and the significance of such effects,
  - use of mitigation for project-related incremental effects, and
  - use of regional approaches for managing such effects.

Numerous methods and technologies were used in this study, with many representing first-time developments. Examples of the methods and technologies used include RFFA matrices; conceptual models for analyzing the historic, current, and future environmental sustainability of the six key VECs or indicators listed above; habitat models; indicators and indices; dynamic scoping; VEC-related modeling; prospective analyses; and scenarios for alternative futures. These methods and technologies are transferrable to other navigation-related water resources projects; in addition, they are also scalable and adaptable to other types of water resources projects.

Mitigation and management of the effects of physical, social, and institutional changes were primarily addressed via use of the environmental sustainability findings. The USACE expert elicitation process was used to address local mitigation and regional management needs for the aquatic ecological resources and the riparian/floodplain ecological resources (Canter and Rieger 2005). In addition, planning for an adaptive management program was accomplished.

3.3.5 Addressing CEAM within a Canadian river basin

Sullivan (2009) prepared a CEAM study for the North Saskatchewan River Basin in Alberta, Canada. The study was associated with an Integrated Watershed Management Plan (IWMP). It addressed four scenarios of potential development over a 100-year timespan; they were examined in relation to physical and use changes (agriculture, forestry, urban, and petrochemical industry) and their cumulative broad-scale effects on biodiversity, landscape integrity, and water quality and quantity. For example, the study examined how gradual encroachment of human development and related impacts on watershed functions will affect watershed values. The four scenarios were titled: (1) Business-as-Usual, (2) Business-as-Expected, (3) Best Practices and Green Cities, and (4) Best Practices, Green Cities, and Climate Change. The physical changes were illustrated

by urban and residential or natural and agricultural footprints and their cumulative detrimental effects on biodiversity, landscapes, and water quality. Projections showed significant expansion of urban and residential uses at the expense of natural and agricultural uses. Changes in the landscape composition would result in cumulative changes in surface water yield and runoff. Wetland losses would result in values well below designated thresholds and thus were a serious concern in all scenarios.

The study was structured around the use of a simulation model known as ALCES© (A Landscape Cumulative Effects Simulator). The model provides a comprehensive approach to simulating and evaluating a broad range of effects from a wide variety of land uses over time. In Sullivan (2009), the selected VECs and indicators included: (a) Biodiversity - index of native fish integrity; (b) Landscape Integrity - percent of basin defined as "human-disturbed," road density, and percent wetland cover; (c) Water Quality - indices of landscape-level runoff of phosphorus, nitrogen, and sediment; and (d) Water Quantity - index of main stem river flow and indices of proportion of river water borrowed and consumed.

The ALCES model appears to be a useful tool for examining cumulative effects of future watershed growth scenarios on environmental services. The concepts and principles would also be transferable to other basin-wide studies.

Further, the simulation results were used to highlight potential areas of needed mitigation and restoration, and to establish priorities for policy changes. Strategies should be favored that emphasize reductions in point- and non-point pollution as well as protection and restoration of aquatic ecosystems including lakes, wetlands and riparian areas. Such ecosystems have the potential to increase resilience and mitigate potential effects of climate change. Restoring the watershed to more acceptable levels of biodiversity, landscape, and water quality would likely require considerable mitigation of existing effects of urbanization and agriculture, including restoration of riparian areas and reductions in non-point source pollution.

To summarize, this case provides useful information for predicting future conditions under future scenarios and for using indicators to model the consequences of PSI changes associated with each scenario. The results yielded an integrated cumulative effects assessment tool which can be

used by decision makers and stakeholders for determining desired watershed growth.

3.3.6 Establishing reference conditions for stream biological assessments

Biological indices can be a useful tool for organizing data and information into a composite representation of the biological conditions within various reaches of a stream. Such indices can also be used to establish “reference conditions” (historical baseline conditions). This information is particularly important in CEAM studies. Time-related changes in biological conditions can be useful in connecting land use changes to changes in biological indices. Further, predictions of future without and with-project stream conditions can be aided by information on reference conditions and their changes over time.

To provide an illustration, Stoddard et al (2006) examined the concept of a reference condition for streams and rivers. The thrusts of the study included a new term reserved for describing a condition in the absence of human disturbance, and the need for related terms that describe conditions at varying levels of human disturbance. Such disturbances result from physical changes associated with human-induced alterations of land use and landscape including descriptions of effects of these activities on the structure and function of aquatic ecosystems and their biota. The proposed terminology for degrees of disturbance was classified as: Minimally Disturbed Condition (MDC), Least Disturbed Condition (LDC), Historical Condition (HC), Best Attainable Condition (BAC), and Reference Condition for Biological Integrity (RC (BI)).

The terminology in the preceding paragraph is associated with a conceptual model-based analytical framework which can be used to define RC(BI). For example, the term RC(BI) should be reserved for depicting the “naturalness” of the biota (structure and function), with that naturalness implying the absence of significant human disturbance or alteration. Criteria for categorization into one of the above condition classes can also be developed on a site-specific basis. A concern expressed was one of circularity (i.e., the structure of the biotic assemblage itself should not be used to classify sites as either reference or disturbed). This clarification would avoid any preconceived notions about the structure and composition of biotic assemblages at a “typical”' reference site.

Methods and technologies included reviews of traditional concepts used in determining reference conditions and the European Union's Water Framework Directive (WFD), and further, the development and use of a set of defined criteria that, in total, describe the characteristics of sites in a region that are the least exposed to stressors. The concepts for delineating reference conditions are transferable because the purpose of the concept is to further clarify and propose better definitions of reference conditions used in conducting assessments of the integrity of water bodies everywhere. Finally, mitigation and management of PSI changes were not addressed by Stoddard et al. (2006). This is noted because the paper itself was focused on the development and use of the tool, and not its potential use for mitigation and management planning.

3.3.7 Ecological designs for water resources projects

Increasing attention is being given to ecosystem-based management of water resources. As a result, greater interest in the historical to current to future sustainability of aquatic and riparian habitats has occurred. Scientific connections between water flow and water quality modeling and ecosystem-related modeling are being explored in relation to traditional projects involving dams, levees, and navigation channels, as well as to ecological restoration of wetlands and aquatic and riparian habitats. In fact, "ecological designs" of varieties of types of water resources projects are being explored. Such explorations incorporate physical changes in design features and parameters and changes in operational practices.

To illustrate this trend, Herricks and Suen (2006) discussed changes in design considerations for water resources projects which are focused on ecosystem sustainability and the integration of eco-hydro-geomorphic systems perspectives. This case study also explored principles associated with ecological engineering for individual projects and overall watershed management. The foundations for these perspectives are the ecosystem approach and the watershed protection approach for both planning and management. Such emphases have been incorporated in the relatively recent ecosystem restoration policies and practices of USACE. One simple example from ecosystem restoration is the potential goal of restoring a river reach or its entire length to a more naturalized system. The goal may require the removal of man-placed structures and the promotion of natural ecological processes.

Herricks and Suen (2006) included helpful discussions of physical changes leading toward "ecological designs" for projects. Attention was given to the use of physical habitat and water quality as the basis for design parameters. No analytical framework was described per se; however, it would be necessary in an actual design process. Rather than providing information on specific methods or technologies, emphasis was given to concepts and fundamental principles. Such concepts and principles are transferrable. To conclude, this case contains useful ideas related to possible more-pronounced future trends toward ecological design.

3.4 Comparative discussion of case studies

Table 1 contains summary information derived from the seven case studies. To provide for consistency in the comparisons, five topics are addressed for each case: (1) features, (2) environmental effects, (3) analytical framework(s), (4) methods and technologies, and (5) mitigation and management of PSI changes. The comparative information displayed in Table 1 reveals the points listed below.

- The study features are unique for each case.
- The addressed environmental effects are appropriate for examining experienced or potential effects from the studied PSI changes.
- While the listed analytical frameworks are diverse, they each provide a relevant structure for the included scientific and policy issues.
- The identified methods and technologies are pertinent for the PSI changes and focus of each case.
- Less direct attention was devoted to mitigation and management in the case studies; however, the effects findings that result from each study could be explored to further address mitigation and management of the changes of concern.

3.5 Lessons learned

Based on this review of seven case studies that are related to institutional changes associated with water resources laws and policies as well as broader environmental laws and policies, the following lessons are noted.

- Institutional changes associated with existing and emerging requirements of water and environmental legislation and policies can be both broad and diverse and can subsequently create diverse environmental effects for streams, rivers, and other aquatic ecosystems.

- Because of potential environmental consequences of such institutional changes, their consideration should be incorporated in the design, construction, operational, and post-operational phases of new projects or within the necessary phases for modifications to existing projects.

Table 1. Comparative information on institutional changes associated with water resources and environmental legislation and policies.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Ex-post reviews of water resources projects (Jacobs 2002)	Use of retrospective analyses of existing or planned new projects to identify actual or potential changes and their consequences	Relationships of project consequences on river flows, environmental flows, water quality, and aquatic and riparian ecology	Corps six-step water resources planning process, and policy sciences (including policy impact evaluations)	Monitoring planning and adaptive management programs; the principles are broadly transferrable in water resources planning	Inferred in relation to decision-making based on results from adaptive management
Retrospective analyses of institutional capacities to reallocate water (Slaughter and Wiener 2007)	Comparative case study of how Idaho and Oregon could respond to increasing needs for water reallocation resulting from climate change and multiple other stressors	Historical to future changes in water demands and uses	Topical approach for analyzing prior water appropriations on the Snake and Klamath Rivers, future water demands, and the use of conjunctive surface and groundwater management	Hydrologic modeling of the implications of re-allocations; the above frame-works and concepts rather than the specific model would be transferable	Use of private water rights for water marketing, and negotiations as appropriate
Hierarchical framework for evaluating impacts from physical changes in dam operations (Burke et al. 2009)	Retrospective studies of the effects of two dams on the Kootenai River; four orders of effects and selected VECs and indicators were used	Spatial and temporal depictions of effects on hydrology, water quality, sediment supply, floodplain and channel morphology, aquatic and floodplain vegetation, invertebrates, fish, etc. were addressed	Conceptual framework connecting operational changes to changes in the four orders of effects	Mathematical modeling, monitoring data, and summaries of pertinent scientific literature	Inferred in relation to monitoring results and use of the analytical framework
Addressing CEAM within NEPA compliance for inland navigation (Canter and Rieger 2005)	CEAM study was conducted for a system investment plan for the 19 locks and dams on the Ohio River main stem	Cumulative effects were identified for 11 VECs and related sub-VECs; detailed analyses were presented for effects on water and sediment quality, fish, mussels, riparian/floodplain resources, water-related health and safety, and water-based recreation	CEQ's 11-step CEAM process and VEC-specific conceptual models	RFFA matrices; conceptual, habitat-related and VEC-related modeling, and scenarios analyses	Included mitigation of the incremental effects of proposed projects, implementation of various management measures for enhancing aquatic and riparian/floodplain ecological resources, and follow-on adaptive management programs

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Addressing CEAM within a Canadian river basin (Sullivan 2009)	CEAM Study for a 100-year future timespan for the North Saskatchewan river basin; four growth scenarios for the basin were evaluated	Cumulative effects on indicators for biodiversity, landscape integrity, water quality, and water quantity were examined	Components within the ALCES simulation model	Indicators and indices for time-related cumulative effects on fish bio-diversity, landscape (land use) integrity, nutrient and sediment runoff, river flows and use, and ALCES simulation model	Simulation modeling results used to prioritize cumulative effects issues, mitigation requirements, and planning for regional cumulative effects management
Establishing reference conditions for stream biological assessments (Stoddard et al. 2006)	Describes concepts, development, and uses of biological indices to establish historical to current conditions in streams and rivers	Connected human-induced alterations to changes in stream-related indicators associated with biological indices; could be used to establish classes of disturbance from physical changes	Conceptual model for connecting alterations to changes in streams or rivers	Reviews of scientific literature and related institutional initiatives; one initiative example is the European Union's Water Framework Directive (WFD)	Not addressed
Ecological design for water resources projects (Herricks and Suen 2006)	Discussion of background, concepts, and principles related to ecological designs	Addresses how ecological designs can be used to minimize water quality and aquatic habitat effects	No specific referrals were noted; however they would be used in an ecological engineering design process	No specific mention of methods and technologies	The concepts and principles of ecological designs are focused on minimizing undesirable consequences of water resources projects, or on enhancing the positive features of preservation or restoration

4 Physical Changes Associated with Land Use Changes in Urbanizing Watersheds

4.1 Introduction

This chapter summarizes eight case studies related to physical changes resulting from urbanization of watersheds. Such urbanization can alter surface water runoff, groundwater recharge, and water and sediment quality in nearby streams, rivers, and lakes. Accordingly, water resources planning studies, including those for specific projects, should account for historical, current, and even future physical changes from urbanization of watersheds within the designated project or plan areas.

Section 4.2 presents the case order. In Section 4.3, Subsections 4.3.1–4.3.8 summarize the eight cases by presenting information derived from using the review form in Appendix A. Subsection 4.4 contains a comparative discussion of the key findings from each case. Finally, several overall lessons are highlighted in Section 4.5.

4.2 Order of case studies

The eight case studies summarized in this chapter are presented in the order listed below.

1. Retrospective water balance study (Haase 2009)
2. Small-scale urban developments (Pauleit et al. 2005)
3. Water quality effects of watershed urbanization (Carle et al. 2005)
4. Mitigation and management of watershed conditions and stream conditions (Booth et al. 2002)
5. Biotic integrity of streams in urbanizing areas (Miltner et al. 2004)
6. Ecological consequences of hydrologic changes in urban streams (Konrad and Booth 2005)
7. Performance study of imperviousness ordinance (Kauffman et al. 2006)
8. Assessing future land use in an urbanizing watershed (Conway and Lathrop 2005).

Each of the eight case studies is directly related to physical changes associated with urbanizing watersheds. Further, all the cases involved retrospec-

tive studies to examine changes related to urbanization as well as resultant changes in quantitative hydrology and streamflows. The first two cases are from Europe—one involves changes in a long-term urban water balance for Leipzig, Germany (Haase 2009), and the other relates to surface water runoff in Merseyside, England (Pauliet et al. 2005). The next three cases give attention to water quality and aquatic ecological changes in Durham, North Carolina (Carle et al. 2005); Seattle and King County, Washington (Booth et al. 2002); and Columbus, Ohio (Miltner et al. 2004). A state-of-the-art review of streamflow changes and ecological consequences is then presented by Konrad and Booth (2005). The seventh case describes an evaluation of the effectiveness of an imperviousness ordinance (Kauffman et al. 2006). The final case illustrates the use of build-out analysis as a long-range planning tool for aiding the mitigation and management of physical changes resulting from urbanizing watersheds (Conway and Lathrop 2005).

4.3 Description of case studies

Following are summary descriptions of each of the eight case studies. The common thread across all cases involves the environmental and water resources consequences resulting from physical changes in urbanizing watersheds.

4.3.1 Retrospective water balance study

Haase (2009) conducted a retrospective study to determine the effects of long-term urbanization on the area-wide water balance for Leipzig, Germany. It is well known that urbanization causes physical changes to occur due to increasing percentages of imperviousness. Such changes can cause incremental and cumulative changes in urban runoff, evapotranspiration, and groundwater recharge, as well as increases in water demand and types of uses. Changes in water quality can also take place; however, no attention was devoted in this study to the water quality impacts of urban land-use changes and the increasing occurrence of impervious cover. A study period from 1870 to 2003 was utilized. Monitoring data on land-use changes, precipitation, and evaporation were used to examine changes in runoff, evapotranspiration, and recharge. A concluding comment was, “The long-term observation of urban growth and sprawling land consumption has proven that it is the cumulative impact of land use change and surface scaling, rather than the short-term consequences that is likely to impair the urban water balance” (Haase 2009). Finally, it should be noted

that the emphasis of this urban development study was on water quantity; no attention was given to the water-quality implications of urban sprawl.

The quantitative analytical framework used in this study was based on a conceptual model. Further, two water balance models were used: ABIMO (a German acronym) and Messer's model. In addition, land-use data were compiled and included within a GIS. The conceptual approach and models used would be, in principle, transferable to other studies of urban sprawl.

Finally, there was no discussion of mitigation and/or management of physical changes. However, it could have been addressed by using the study findings.

4.3.2 Small-scale urban developments

Pauleit et al. (2005) retrospectively examined the environmental effects of urban land use changes and the dynamics of greenspace, focusing specifically on changes in land use and land cover in 11 residential areas in Merseyside, northwestern England. They further assessed how such changes were manifested with regard to wildlife habitats and other environmental services (e.g., soil infiltration). They found that the amount of greenspace lost was related to socio-economic status, with more affluent, low density areas losing more greenspace due to infilling over the 25-yr retrospective period. They also found that most changes over the 25-yr period resulted from small-scale individual developments which have been constrained, but not directed, by planning law.

An analytical framework was developed wherein modeling of land cover changes was connected to three environmental parameters: surface temperature, rainfall runoff, and greenspace diversity. In turn, these changes were related to the socioeconomic status of the 11 residential areas. The methods and technologies utilized within the study included:

- aerial photography and Landsat to map land use and land cover;
- diversity models to assess biodiversity potential as a function of greenspace cover and diversity;
- tree cover as an indicator to distinguish between high and low economic status;
- environmental models using land cover as the main input to indicate environmental impacts of urbanization in planning situations where

the feasibility of collecting large quantities of environmental data is limited; and
- index of multiple deprivations to distinguish between more affluent and more deprived areas.

Pauleit et al. (2005) went on to suggest that, "Community mapping could be a means to include local knowledge in the environmental evaluation of urbanization processes." Further, they noted the transferability of the framework, methods, and technologies to a variety of settings to examine how land-use and land-cover changes affect the environment, and whether these changes are driven in part by socio-economic status. It was also suggested that the approach used was the most appropriate for a survey in small sample areas and with limited financial resources.

With regard to management of physical changes related to urban settings, emphasis was given to the need to critically review concepts such as urban densification and the need to give more weight to the preservation and management of urban green-spaces. The authors also stated that compaction of existing settlements has been suggested as a strategy to counter urbanization trends. Finally, Pauliet et al. (2005) observed that while urban development may be desirable, environmental and landscape concerns need to be given greater consideration to achieve more sustainable development. Further, designation of greenspace conservation areas could also be used as an instrument to control infill development.

4.3.3 Water-quality effects of watershed urbanization

This case study was focused on changes in selected water quality indicators resulting from associated physical changes in the types and patterns of land usage in six urbanizing watersheds in Durham, North Carolina. The selected indicators included total phosphorus, total kjeldahl nitrogen, total suspended solids, and fecal coliforms. These indicators are reflective of greater intensities of lawn fertilizer use, lesser ground cover in construction locations, absences of sewerage systems, and prior land use. This case supports the premise that urbanizing watersheds are a common source of water-quality effects in urban streams and rivers.

No analytical framework was specifically described; however, the study features and analyses were logical, scientifically-defensible, and consistent with other similar types of urbanization studies. Several methods and technologies were used to summarize and display information, develop

cause-effects relationships, and support regression modeling. The tools used included:

- land use mapping and GIS;
- selected indicators for representing urbanization, type of urbanization, city services, natural watershed features, rainfall, impervious surfaces, water quality (four quality indicators noted in paragraph above), and census information;
- principal component analysis; and
- multiple linear regression models for relating physical changes in urbanization to changes in local water quality.

A key finding through the development of multiple linear regression models was that the four water-quality indicators were related to development density, urbanization type, and access to city services. This study was data intensive and time consuming; however, the study framework, concepts, and methods and technologies would be transferable to other studies highlighting water-quality effects associated with urbanization in local watersheds. Mitigation and management of changes in water quality were not addressed because the study focus was on cause-effects relationships. However, the resultant regression models could be used to explore strategies such as imperviousness ordinances; designations of protected land areas or water zones in local streams or rivers; and potential needs for ecosystem restoration efforts.

4.3.4 Conditions

For over two decades, Seattle and King County in the State of Washington have implemented progressively more demanding strategies to protect aquatic resources and declining salmon populations from cumulative changes due to urbanization (Booth et al. 2002). Protection activities have resulted from both CWA requirements and ESA listings. Land uses within King County watersheds range from forested areas to industrial zones and historically urban and newly urbanizing locations. As physical changes in land uses and cover occur, resultant changes in water quality and aquatic habitat also take place. Runoff and streamflow changes occur in urbanizing watersheds, and these changes can, in turn, cause dramatic changes in flooding, erosion, sediment transport, and channel morphology. These physical changes can affect aquatic biota via changes in flow regimes, aquatic habitat structure, water quality, biotic interactions, and food sources.

Over several decades, empirical relationships have developed between watershed conditions and their changes and between stream conditions and their changes. Many of these studies identified an imperviousness threshold level of 10%—that is, when watershed imperviousness exceeded 10% of the land area, rapid declines in biotic diversity occurred.

Booth et al. (2002) addressed physical changes in land uses in the Seattle watershed area, with particular attention given to changes in forest cover. Stream conditions were addressed via selected indicators including quality of fish habitat, imperviousness areas, riparian conditions, and benthic indices of biotic integrity (B-IBI) scores for Puget Sound lowland streams. Several hydrologic models (one example is the Hydrologic Simulation Program - Fortran*; see Bicknell et al. 1997 for user's manual), water planning tools, and effectiveness studies of mitigation and restoration strategies were utilized in this study. While no overall analytical framework was described, a systematic, logical, and scientifically-defensible plan was utilized. Accordingly, the study approach, methods, and technologies would be transferable to other studies involving urbanizing watersheds.

A major portion of this study dealt with hydrologic mitigation through structural means that involve new technologies and approaches, and through hydrologic restoration via watershed planning. Some examples of newer technologies and concepts, including both structural and non-structural measures, which were examined included:

- watershed planning with clustered developments that protect half or more of the forest cover, preferentially in headwater areas and around streams and wetlands to maintain intact riparian buffers;
- maximum of 20% total impervious area, and substantially less impervious areas through the widespread re-infiltration of stormwater;
- on-site detention, realistically designed to control flow durations (not just peaks);
- riparian buffer and wetland protection zones that minimize road and utility crossings as well as overall clearing; and
- no construction on steep or unstable slopes.

* The Hydrological Simulation Program–Fortran is a set of computer codes developed in cooperation with the Environmental Research Lab of the US EPA in Athens, George. The software can simulate the hydrologic (and associated water quality) processes on pervious and impervious land surfaces and in streams and well-mixed impoundments.

In addition, it was noted that preservation of aquatic resources in developing areas in King County watersheds will require integrated mitigation and management, which must include impervious-surface limits, forest-retention policies, stormwater detention, riparian-buffer maintenance, and protection of wetlands and unstable slopes (Booth et al. 2002). A final emphasis was on combining various mitigation and management efforts for controlling the physical changes/ effects of urbanizing watersheds.

4.3.5 Biotic integrity of streams in urbanizing areas

The biological health of streams or rivers in urbanizing areas, as measured by an Index of Biotic Integrity (IBI), is negatively correlated with the amount of urban land use in the surrounding watershed (Miltner et al. 2004). That is, the IBI score decreases as the land use increases from undeveloped lands to include development projects, urban areas, and other activities. Further, mitigation or management measures are available to reduce negative impacts on the biological health of local streams or rivers. This study examined the relationship between urban land use and stream or river IBIs in historically urbanized areas in Columbus, Ohio and in three streams in the rapidly urbanizing metropolitan area in the same city. The changes included historic disturbances of streams, a doubling of the population density from 1990 to 2000, and increased recognition of the environmental consequences of development activities.

This study focused on: (a) stream-related physical changes resulting from the environmental consequences of development, (b) equating levels of disturbance with percent of impervious cover, (c) cumulative effects of multiple stressors, (d) effects to fish species occurrences, (e) interactions among allied stressors, and (f) state-wide leveling-off trends in the number of stream reaches attaining their designated uses. While no specific analytical framework was identified, the study design was logical, scientifically based, and focused on established goals.

Methods and technologies used included IBIs, analyses of co-variance (ANCOVA), regression of IBI scores against the percent of urban land use and Qualitative Habitat Evaluation Index (QHEI) scores, and Scott and Helfman's time course of homogenization wherein the effect of disturbance is reduction or extirpation of highly specialized species or those on the edge of their range (in Miltner et al. 2004). Additional tools included GIS, various indicators, scenarios, sustainability analysis, conceptual models, build-out analysis (impervious cover), designated

aquatic life uses, Landsat data, classification of impact types, and number of highly sensitive species. Many of these methods and tools are already widely used in various aquatic environment and other impact studies. These methods and tools are readily transferable to other studies.

Mitigation and management of physical changes associated with urbanization and its resultant consequences in the aquatic environment were also discussed. Examples of such measures included (Miltner et al. 2004):

- regulation of construction practices,
- maintenance of floodplains and riparian buffers,
- smart growth legislation,
- aggressive stormwater regulations,
- restoration strategies,
- use of best management practices (BMPs),
- comparison with multiple state requirements,
- performance bonds for stormwater permittees,
- riparian buffers, and
- limits on development.

4.3.6 Ecological consequences of hydrologic changes in urban streams

Urbanizing watersheds are characterized by physical changes in land use and land cover, and by changes associated with conversions from natural runoff patterns to the construction and use of engineered drainage systems and related infrastructure. The consequences of these changes from urbanization can be manifested by changes in stream hydrologic patterns and associated ecological characteristics. Konrad and Booth (2005) conducted a comprehensive review of published literature and developed a conceptual model of various relationships between "causative" changes and "consequential" changes.

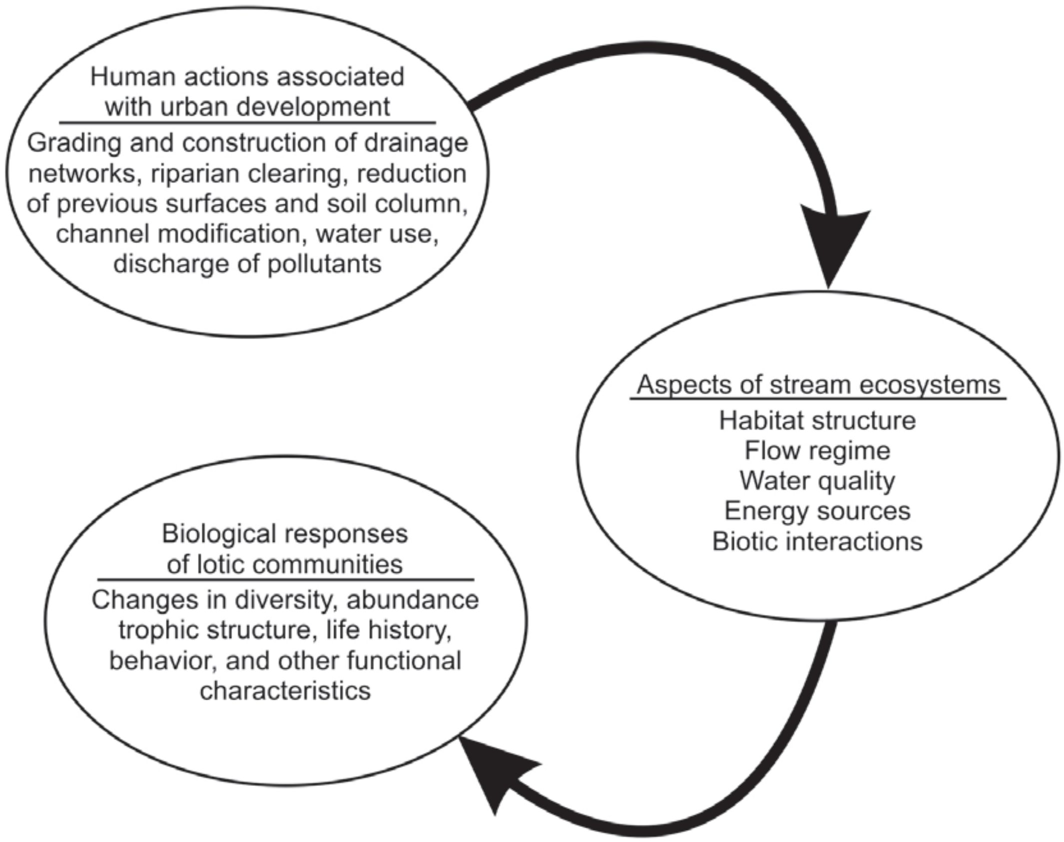
The conceptual model, which also provides an analytical framework, is in Figure 2 (Konrad and Booth 2005). Depicted in the model are human actions associated with urban development, aspects of stream ecosystems which can be altered, and biological responses of lotic communities. One major category of causative changes is associated with modifications in the quantity and timing of runoff to streams and the resultant rates, volume, and timing of streamflows. Information from eight streams in urbanizing areas across the United States, along with five additional stable reference streams, were used to examine hydrologic modifications. These changes

can cause modifications in stream ecosystems and their ecological significance. Four hydrological changes from urban development that can have significance to aquatic ecosystems include increased frequency of high flows, redistribution of water from base flow to storm flow, increased daily variation in streamflow, and reduction in low flow. Biological responses of lotic communities to the above hydrologic modifications can include changes in diversity, abundance, trophic structure, life-history, behavior, and other riverine functional characteristics. Finally, although general cause-and-effect relationships can be identified, it should be remembered that site-specific factors can influence these relationships; examples include the river's general physiographic context, and the timing and spacing of urbanization projects.

The general method used in this case study included the identification and review of pertinent topical literature and the synthesis of the findings into a "state-of-the-art" paper. Major headings included hydrologic effects of urban development, biological variation associated with streamflow patterns, ecologically significant variation in streamflow patterns, methods for assessing hydrologic changes in urban streams, temporal changes in streamflow patterns at urban and reference streams, framework for assessing the ecological effects of urban streamflow patterns, management responses to hydrologic modification in urban streams, and ecological management goals for urban streams. As can be seen by these headings, this paper contains a valuable summary of accumulated knowledge on the subject area.

The general cause-and-effect relationships described are transferable. They can be used in planning and evaluation of the potential individual and cumulative effects of development projects in a variety of settings. Further, a brief discussion of mitigation and management responses to hydrologic modifications in urban streams is also included. Examples of such responses include stormwater management, hydrologic restoration, erosion control, use of detention or infiltration ponds, low-impact development measures, and various combinations thereof. Land-use zoning and designated protection areas can also be integrated within mitigation and management responses.

Figure 2. Conceptual model depicting causative changes and consequential changes (Konrad and Booth 2005, 158).



4.3.7 Performance study of imperviousness ordinance

One widely used approach for managing land-use changes in urbanizing watersheds and mitigating their incremental consequences on local streams and rivers involves the passage and enforcement of impervious cover ordinances.

This case study involved a performance evaluation of a 1991 ordinance adopted by New Castle County in Delaware (Kauffman et al. 2006). The ordinance established a maximum of 20 percent impervious cover in designated Water Resource Protection Areas (WRPAs). Increasing impervious areas are of concern due to the associated increases in runoff peak flows and decreases in groundwater recharge and stream base flows. These WRPAs were designated in order to protect the quantity and quality of drinking water by limiting locations of new urbanizing developments. The

designated WRPAs included areas of groundwater recharge, wellhead protection zones for public water supplies, drainage areas above man-made reservoirs serving as water supplies, and limestone aquifers.

The case focuses on a retrospective study of the implementation and effectiveness of the ordinance. The study period, which extended from 1991 through 2001, included a review of 138 new developments subjected to the ordinance. The analytical framework involved GIS-related examinations of physical changes in land use over time in the WRPAs, delineation of the types of land use changes, and calculation of the cumulative impervious cover areas. The types of land uses included single family residential, multi-family residential, office/commercial, industrial, transportation/utility, institutional, public open space, wooded, agriculture, water/wetlands, and vacant. Typical impervious cover percentages by land-use type were utilized to calculate the overall percentage of impervious cover within the WRPAs. A spreadsheet model for calculating the cumulative impervious cover was utilized.

The general findings of this study were that the composite impervious cover of the 231 square kilometers of WRPAs in New Castle County was 15% (Kauffman et al. 2006). The cover data ranged from 7% in recharge areas to 41% in several wellhead protection areas. The study revealed that code variances had been allowed on occasion. As a result, recommendations were made regarding non-allowance of code variations in more developed WRPAs and those already exceeding the 20% level. Also, recommendations were made regarding the acquisition of park lands and open space in prioritized areas.

The analytical framework and methods used in this study would be useful for other studies focused on cumulative increases in impervious cover due to development projects occurring over time. Opportunities for mitigation and management of the changes were addressed via effective use of the 1991 ordinance.

4.3.8 Assessing future land use in an urbanizing watershed

Urbanizing watersheds can be subject to physical changes which were initiated in the past, continue currently, and may well extend into future decades. Specific initiating points may be difficult to identify, and future time periods may also contain many uncertainties. One concept which can be used to address future land uses in a watershed involves “build-out analy-

sis." A key feature of such analyses is the use of alternative futures (or scenarios). Accordingly, a build-out conceptual or actual model can be used to examine the form and results of a fully developed landscape, while avoiding the complexity of precisely predicting when urbanizing physical changes will occur (Conway and Lathrop 2005). Further, use of scenarios is becoming more commonplace within environmental impact studies (Duinker and Greig 2007).

A recent study of an urbanizing watershed incorporated build-out analyses (Conway and Lathrop 2005). Rather than considering time-specific physical changes, assumptions regarding land-use changes were made to yield four alternative futures (scenarios) for build-out. The four scenarios, which were developed for the Barnegat Bay coastal watershed in New Jersey, included one based on current land-use regulations, another on down zoning (more land per dwelling), another on protecting a buffer around wetlands, and the fourth involving open space protection. Several indicators of the incremental consequences of these scenarios were studied; they included impacts on water demand, urban non-point source pollution, and terrestrial habitat fragmentation.

A land use build-out model provided the analytical framework for the case study. This spatially explicit model was developed to project future land uses within the watershed. Digital land use/land cover data for 1995 was used to establish current conditions. The spatial applicability of state land use-related regulations was also considered; examples included the New Jersey Freshwater Wetlands Act, Tidelands Act, Coastal Area Facilities Review Act, and the Pinelands Commission's Management Plan. Allowable intensities of development were procured from these regulations.

The four build-out scenarios were based on the following specific information as described below (Conway and Lathrop 2005).

- *Current regulations scenario* - based on municipal zoning, state environmental regulations, and existing protected open space.
- *Down-zoning scenario* - current regulations scenario, but with the minimum lot size of future residential development outside sewer service areas forced to be at least 1.3 ha (this represents an increase in the minimum lot size).

- *Large buffer scenario* — the down-zoning scenario with undevelopable buffer zones increased to 91 m around all freshwater wetlands and streams, and the buffer zone around all tidal areas increased to 152 m.
- *Open-space scenario* — the down-zoning scenario with an aggressive plan to protect open space.

The selected indicators for water demand included the number of dwelling units and the number of people, on average, living in each type of unit. The indicator for urban non-point source pollution was the percentage of impervious cover associated with each type of land use (residential, commercial, industrial, infrastructure, etc.). Indicators for terrestrial habitat fragmentation included percentage of total area for natural cover (landscape composition), and a contagion index (interspersion and dispersion) and correlation length (measure of patch extent). The study findings regarding each scenario indicated that problems would occur regarding water demands exceeding supply, local area water-quality problems, and further fragmentation of terrestrial habitat.

The methods and technologies used included a land-use build-out model, land-use/land-cover data and GIS, analyses of current regulations, selected environmental indicators, and comprehensive literature reviews. These tools are straightforward, understandable, transparent, and transferrable. Mitigation and management of changes was a key theme, and discussions were included on limiting the amount of impervious surface cover in the watershed and increasing planning throughout the Barnegat Bay watershed.

4.4 Comparative discussion of case studies

Table 2 contains summary information derived from the eight case studies. To provide for consistency in the comparisons, five topics are addressed for each case: (1) features, (2) environmental effects, (3), analytical framework(s), (4) methods and technologies incorporated, and (5) mitigation and management of changes. The comparative information displayed in Table 2 reveals the points listed below.

- The specific study features are unique for each case.
- The addressed environmental effects are appropriate for examining experienced or potential effects from the studied causative changes in land use/land cover.

- While the listed analytical frameworks are diverse, they each are scientifically defensible and consistent with similar types of studies.
- The identified methods and technologies are wide-ranging; however, they are pertinent for the causative and consequential changes and focus of each case, and they are transferrable to other changes-related studies.
- The types of tools routinely included land-use information, GIS, indicators and indices, and simple to sophisticated mathematical models.
- Most of the cases devoted attention to mitigation and management; a common theme was the need for using composite strategies involving regulations, hydrologic controls, growth planning, protection areas, and, as needed, restoration.

4.5 Lessons learned

Based on this review of eight case studies related to urbanizing watersheds and their associated physical changes on the water environment, the following lessons are noted.

- A robust literature base is available for addressing physical changes from urbanizing watersheds and their consequences to runoff, stream flows and geomorphology, water quality, and aquatic ecosystems.
- Scenario analyses involving alternative futures can be a useful tool for bounding potential future causative and consequential changes.
- Mitigation and management of changes should be developed from a holistic perspective—that is, a range of options and their effectiveness should be considered, along with various combinations thereof.

Table 2. Comparative information on physical changes in urbanizing watersheds and their environmental and water resources consequences.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Retrospective water balance study (Haase, 2009)	Retrospective study of the incremental effects of long-term urbanization on the area-wide water balance for Leipzig, Germany.	Physical changes in land use from 1870 to 2003, and resultant changes in runoff, evapotranspiration, and recharge; emphasis was given to water quantity.	Conceptual model and two water balance models for urban or urbanizing areas	ABIMO model and the Messer's model, land use data and GIS; concepts and principles are transferrable to other studies of urban sprawl.	No discussion of mitigation and management of changes.
Small-scale urban developments (Paulleit et al. 2005)	Retrospective study, over a 25-yr period, of physical changes in land use and land cover in 11 residential areas in Merseyside, England; resultant changes in wildlife habitat, rainfall runoff, and greenspace diversity were also examined.	Changes in biodiversity potential of wildlife habitat, rainfall runoff, and losses of greenspace diversity; economic characteristics of the residential areas were also correlated with such changes.	Modeling of land cover changes in relation the surface temperatures, rainfall runoff and greenspace diversity	Aerial photography and Landsat environmental indicators and indices, diversity models and economic indices; concepts and principles are transferrable to other locations.	General discussion of mitigation and management issues.
Water quality effects of watershed urbanization (Carle et al. 2005)	Study of water quality changes resulting from physical changes in land use in six urbanizing watersheds in Durham, North Carolina.	Changes in total phosphorus, total kjeldahl nitrogen, total suspended solids and fecal coliform concentrations in local streams	Use of scientifically-defensible approach which is consistent with similar types of studies.	Land use mapping and GIS, indicators for addressing several variables, principle component analysis, and linear regression models; these tools and concepts are transferrable to other studies.	Not specifically addressed; however, regression models could be used for planning purposes.
Mitigation and management of watershed conditions and stream conditions (Booth et al. 2002)	Comprehensive study of physical changes in land uses and resultant changes in water quality in Seattle, King County, Washington; specific attention given to hydrologic mitigation measures and other ecological protection efforts	Changes in streamflow, geomorphology, water quality, aquatic habitat structure, and biotic interactions	Use of scientifically-defensible approach which is consistent with similar comprehensive studies.	Hydrologic models, indicators for stream conditions, and evaluation of the effectiveness of mitigation and restoration strategies; concepts and principles are transferrable to other studies.	Several strategies were described, with combinations of approaches recommended for different areas.
Biotic integrity of urbanizing areas (Miltner et al. 2004)	Study of relationships between urban land use and associated changes and the resultant IBIs in streams and rivers in Columbus, Ohio.	Stream-related IBIs	Use of scientifically-defensible approach which is consistent with other studies of IBIs.	IBIs, regression analyses, QHEIs, GIS, Landsat, conceptual models, and sustainability analysis; the concepts and principles are transferrable to other studies.	Discussion of several methods; examples include smart growth legislation, stormwater regulations, restoration strategies, riparian buffers, etc.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Ecological consequences of hydrologic changes in urban streams (Konrad and Booth 2005)	Comprehensive review of published literature and synthesis of information into topical themes related to causative and consequential changes.	Changes in runoff patterns, streamflows and flow regimes; stream habitat trophic structure, diversity, and abundance; and other functional characteristics	Conceptual model	Use of hydrologic information from eight urbanizing areas and five reference streams, and comprehensive review and synthesis of pertinent published literature	Brief summary information on multi-component strategies.
Performance study of imperviousness ordinance (Kauffman et al. 2006)	Retrospective study of the performance evaluation of the effectiveness of a 1991 imperviousness ordinance for WRPAs in New Castle County, Delaware.	Primary focus was on changes of land-use patterns from 1991–2001, and calculations of percentages of impervious cover within WRPAs in New Castle County.	GIS-related examinations of changes in land usage over time, the types of such land use changes, and calculation of the cumulative impervious cover areas.	GIS, land use/land cover information, typical cover percentages by land use type, and use of a spreadsheet model to calculate the overall percentages of impervious cover in WRPAs; these tools are transferrable to other similar studies	Potential mitigation and management strategies were identified, along with continued use of the 1991 ordinance.
Assessing future land use in an urbanizing watershed (Conway and Lathrop 2005)	Use of build-out analysis and four scenarios to examine physical changes in land uses in the Barnegat Bay watershed in New Jersey, and to consider consequences on water demand, urban non-point pollution, and terrestrial habitat fragmentation.	The consequences of land-use changes were examined in relation to water use and future demand, increases in non-point source pollution, and terrestrial habitat fragmentation.	Land-use build-out model used for a current regulations scenario, down-zoning scenario, large-buffer scenario, and open-space scenario.	Model, land use/land cover data and GIS, environmental indicators, analyses of regulations, and literature reviews; the concepts, principles, and literature would be transferrable to other build-out studies.	Discussions related to limiting the amount of impervious surface cover in the watershed.

5 Physical Changes Associated with Land-Use Changes and Development Projects in Watersheds

5.1 Introduction

This chapter summarizes four case studies related to causative physical changes in watersheds resulting from land-use changes and development projects. Further, consequential changes in the water environment are also addressed. Such changes can alter surface water runoff, groundwater recharge, and water and sediment quality in nearby streams, rivers, and lakes. Changes in riparian and aquatic ecosystems can also occur. Accordingly, water resources planning studies, including those for specific projects, should account for historical, current, and even future changes from watersheds within the designated project or plan areas. Finally, in contrast to Chapter 4 which emphasized urbanizing areas within watersheds, the case studies in this chapter contain a “watershed as a whole” perspective.

Section 5.2 presents the case order. In Section 5.3, Subsections 5.3.1–5.3.4 summarize the four cases by presenting summary information on each case derived from using the review form in Appendix A. Section 5.4 contains a comparative discussion of the key findings from each case. Finally, several overall lessons are highlighted in Section 0.

5.2 Order of case studies

The four case studies summarized in this chapter are presented in the order listed below.

1. Human and landscape interactions in a watershed (Kuczenski et al. 2000)
2. Problem formulation for a watershed ecological risk assessment (Cormier et al. 2000)
3. Watershed urbanization effects on streamflow characteristics and riparian vegetation (White and Greer 2006)
4. Development-related cumulative effects to riparian ecosystems (Stein and Ambrose 2001).

Each of these four case studies is associated with a specific watershed and involves both retrospective and prospective analyses. The first case study addresses relationships between land use and demographic information and applies principles of landscape ecology for future considerations related to the Kickapoo River watershed in southwestern Wisconsin (Kuczenski et al. 2000). The second case illustrates how ecological risk assessment can be used as a tool for addressing historical and future physical changes in the Big Darby Creek watershed in central Ohio (Cormier et al. 2000). Watershed urbanization is then addressed for the Los Penasquitos Creek watershed in Southern California (White and Greer 2006), with emphasis given to consequential changes in streamflow characteristics and riparian vegetation. Finally, a case study involving multiple Section 404 permits in the Santa Margarita watershed in Orange County, California, is described (Stein and Ambrose 2001). Emphasis in the final study is given to cumulative physical changes from the development projects and their consequences on riparian ecosystems; use of a Special Area Management Plan (SAMP) is also addressed.

5.3 Description of case studies

Following are summary descriptions of each of the four case studies addressed in this chapter. The common thread across all cases involves the environmental and water resources consequences resulting from physical changes in land use/land cover and development projects within watersheds.

5.3.1 Human and landscape interactions in a watershed

This study examined the relationships between land use, landscape ecology, and demographic indicators in the Kickapoo River watershed in southwestern Wisconsin (Kuczenski et al. 2000). The analytical framework involved the use of GIS to integrate Landsat™ Thematic Mapper land-cover data with census-derived housing density data. Land cover was used as an indicator of the biophysical landscape structure, and patchiness provided insights into ongoing processes and anticipated species in the primarily forested watershed. Housing density was selected to represent the social structure in the watershed. Principles of landscape ecology were used to develop an understanding of the structure and functions (processes) of the ecosystems including naturally occurring PSI changes over time.

Societal-induced and natural changes within the watershed included the examples listed below (Kuczenski et al. 2000).

- Landscape changes occurring in response to climatic events, natural and human disturbances, or through species extinction or colonization.
- Forests transitioning from oak-hickory to shade-tolerant maple-basswood in response to human activities in the watershed.
- The expanding, aging human population forecasts that suggest changes in land use and tenure from agriculture to housing.
- The steepness of local area terrain affects settlement patterns, with steeper areas having lower housing densities and less fragmentation; these patterns can affect species composition and landscape structure.

Land-cover data were derived from Landsat satellite imaging. Nine land-cover classes occurred in the watershed: water, barren, urban, wetland, forested wetland, coniferous forest, deciduous forest, grassland, and agriculture. The watershed also had six classes of housing units per square kilometer in census blocks: none, <2, 2–4, 4–8, 8–16, and >16. The GIS was used to overlay land-cover data and housing density data. Additional social and demographic data included: total persons, persons older than 65 yr, portion of population without a high school diploma, portion of population with a professional degree, and persons in different employment categories (e.g., agriculture, forestry, or fisheries; health services; and educational services). Information was also included on vacant housing units, units used for recreational or seasonal purposes, and census-defined farm residences.

The analyses consisted of addressing the multiple relationships between land-use classes, housing density and other census-related data, and the landscape ecology features of the watershed. In so doing, the implications of the above changes were explored.

The methods and tools which were used are readily transferable to other studies where the focus is given to linking biophysical and demographic data within a watershed to describe relationships between humans and the environment. Further, they were useful in demonstrating the relevance of these relationships to management and use of the natural resource base within a watershed.

Natural resources managers and water resources planners may use information from this type of study for managing physical changes, because the interrelationships between human populations and the landscape must be addressed in long-term water resources planning, management, and protection. Water resources planners may wish to focus particular attention on the structural qualities of watershed landscape that promote or impede sustainable aquatic ecological systems. Knowledge of the spatial relationship between water resources and agricultural or higher housing density land can facilitate targeted efforts to improve land use practices.

5.3.2 Problem formulation for a watershed ecological risk assessment

This case involved the Big Darby Creek watershed (a small river watershed) in central Ohio. This watershed was chosen for a pilot study because it is a highly valued ecosystem which is being subjected to numerous physical changes associated with both intensive agricultural practices and suburban encroachment. The study itself focused on a problem formulation process as a basis for conducting an ecological risk assessment (ERA) (Cormier et al. 2000). The numerous changes are typically referred to as multiple stressors or sources in ERA. Attributes of the watershed that make it highly valued include its scenic beauty, high water quality, aquatic diversity in terms of fish and mollusks, and recreational opportunities.

The analytical framework for this case involved the US Environmental Protection Agency's (EPA) ecological assessment framework. Figure 3 displays the three-part (problem formulation, analysis, and risk characterization) ecological assessment framework (US EPA 1992). Figure 4 includes details related to the problem formulation stage (US EPA 1992). Integration of available information involved the assemblage and synthesis of environmental and natural resources data. Examples include land use and history, ecological effects on fish and mollusks, sedimentation, water quality, and altered hydrologic regime, and necessary data for the various selected indices.

The methods and technologies which were used in this case included:

- two conceptual models for exposure of fish and benthic macroinvertebrates (see Figure 5 and Figure 6);
- stakeholder meetings;
- development of management goals and sub-goals;
- historical biological surveys of fish and molluscs;

- identification of threatened and endangered species;
- several biological indices (invertebrate community index, QHEI, indices of biotic integrity, and Shannon diversity index), and modified index of well-being;
- appropriate assessment endpoints (based on management goals which are linked to risks); and
- pertinent comprehensive literature reviews.

The above analytical frameworks, as well as methods and tools listed, would be transferable to other watershed-related, problem formulation studies. Finally, mitigation or management was not discussed in this case study. However, it should be noted that the US EPA's ERA framework includes such emphasis in risk analysis, risk characterization, and stakeholder collaboration focused on risk management.

Figure 3. Generalized three-stage ecological assessment framework (US EPA 1992).

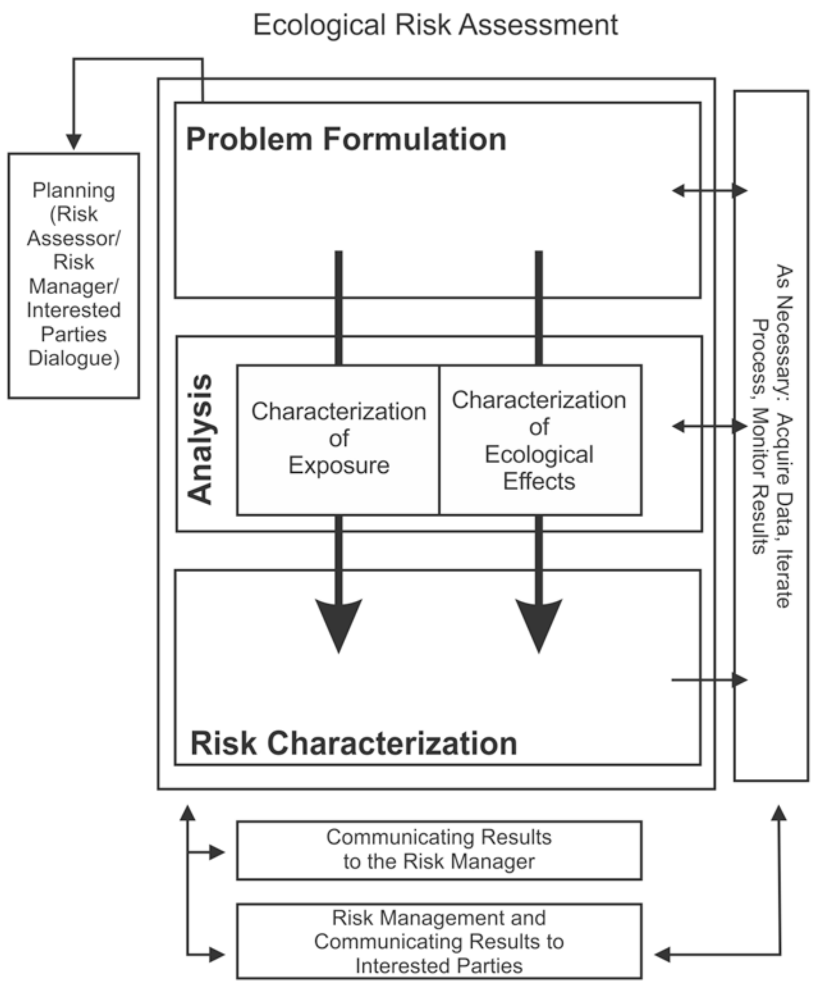


Figure 4. Details of the problem formulation stage of the ERA framework (US EPA 1992).

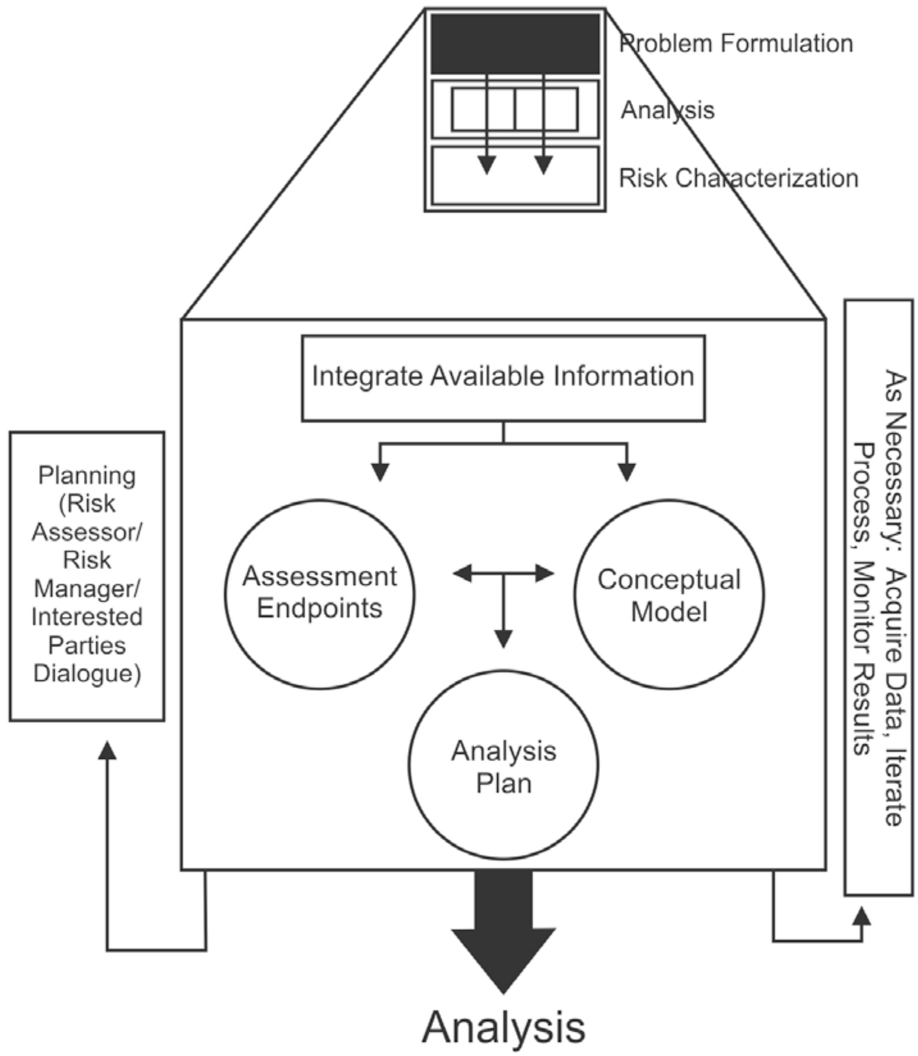


Figure 5. Conceptual model of exposure to fish (Cormier et al. 2000, 1089).

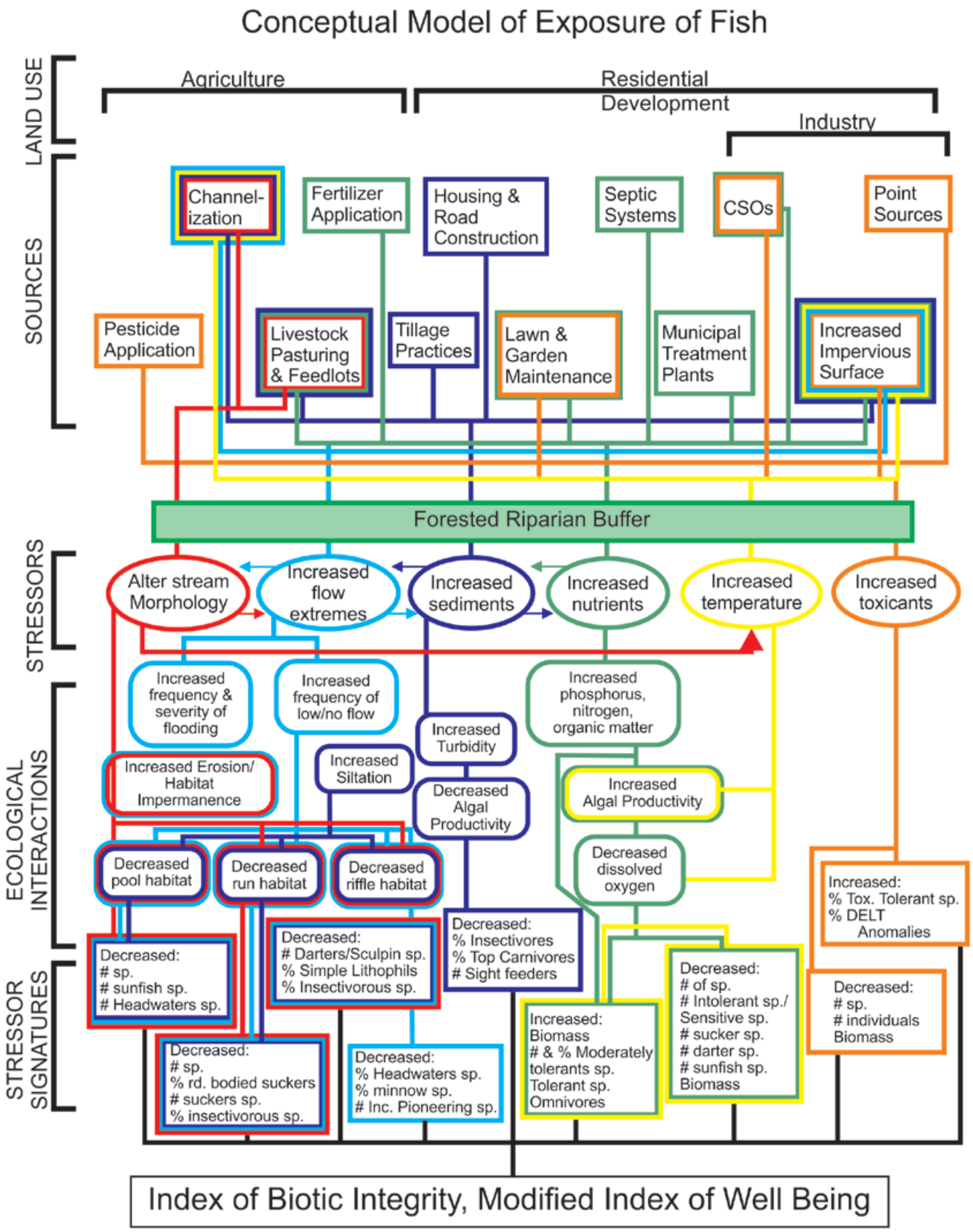
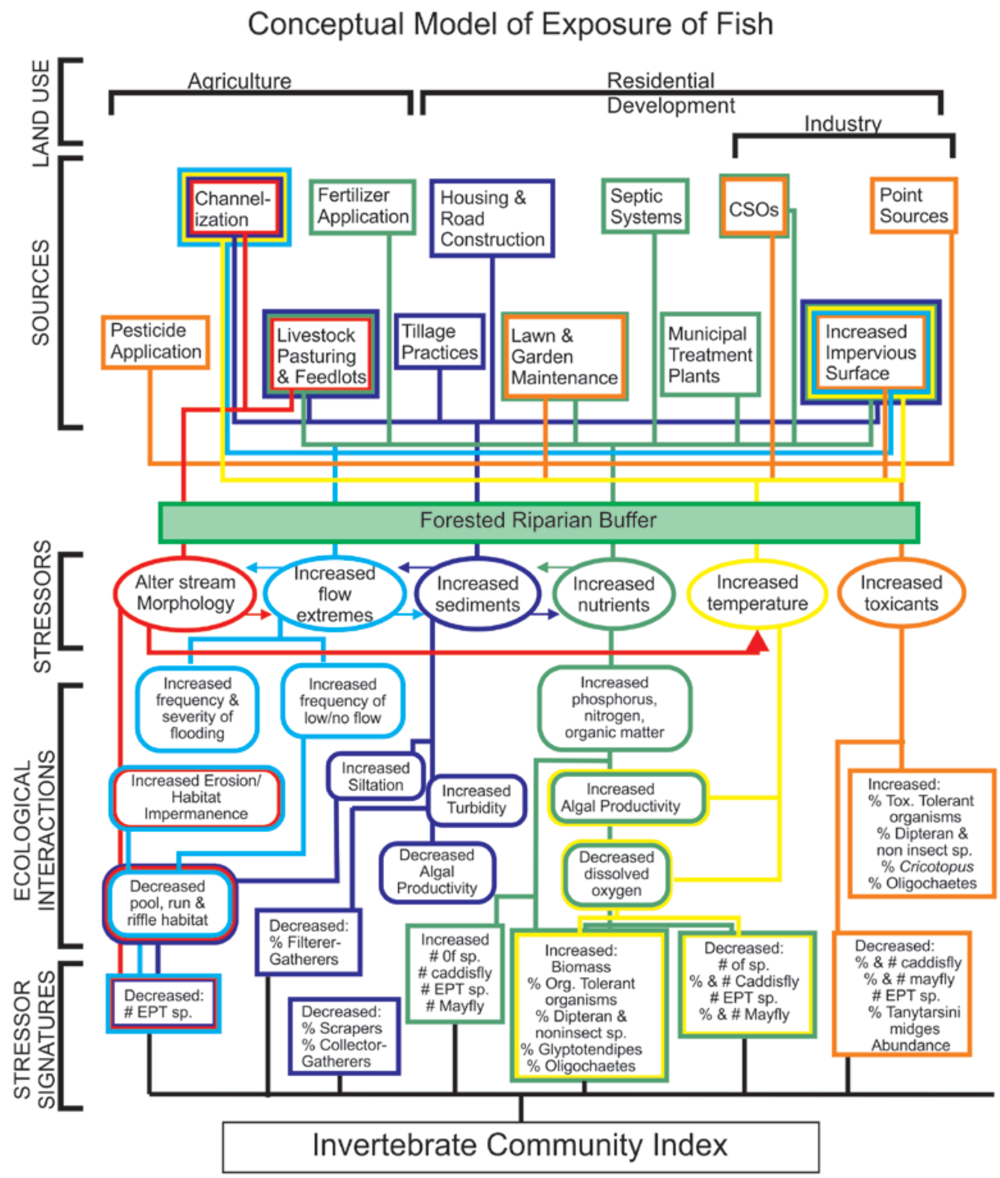


Figure 6. Conceptual model of exposure of benthic macroinvertebrates (Cormier et al. 2000, 1090).



5.3.3 Watershed urbanization effects on streamflow characteristics and riparian vegetation

This case study addressed changes from watershed urbanization and their consequential changes on stream hydrology and riparian vegetation within the Los Penasquitos Creek watershed in Southern California (White and Greer 2006). The watershed area is 15,759 ha, with the discharge into the coastal area occurring via Los Penasquitos Lagoon. Retrospective studies of available information and data were evaluated over the period from

1966 to 2000. The specific study objectives were to: (1) quantify the urbanization of a coastal Southern California watershed; (2) evaluate potential urbanization-induced changes in streamflow characteristics; (3) quantify temporal changes in the distribution of the riparian vegetation community; and (4) evaluate whether these distribution patterns are consistent with observed hydrologic changes (White and Greer 2006).

While no specific analytical framework was used, the study was well-planned and scientifically-defensible. Further, the concepts and principles could be used for other watershed urbanization studies. The data and information which was gathered for the study period included precipitation patterns, runoff, streamflow measurements, aerial images and photographs of temporal and spatial patterns of land use and riparian vegetation communities, land-use maps, and GIS. Land-use changes during the study period included decreases in cattle grazing in the lower basin, increases in urban development in the upper watershed, and decreases in treated wastewater discharges in the lower basin. Regression analyses and ANOVA were also used within this study.

Three time periods were used to evaluate the compiled retrospective data: (1) 1966–1972, the period of treated wastewater discharge and *low* urbanization (<15% urbanization of the watershed); (2) 1973–1987, the period of *moderate* urbanization (≥15% but <25% urbanization); and (3) 1988–2000, the period of *high* urbanization (≥25% urbanization) (White and Greer 2006). Additional information assembled for the time periods included annual hydrologic statistics, flood frequencies, and riparian vegetation community patterns.

The case study results indicated that urbanization of Los Penasquitos Creek watershed has caused the following consequential changes (White and Greer 2006).

- Significant increases in annual median and minimum discharges and dry season runoff
- Increases in flood magnitudes
- Geomorphic changes to stream channel morphology
- Hydrologic changes favoring the expansion of a willow-dominated riparian vegetation community

These consequential changes are a result of physical changes in watershed urbanization which have increased conveyance of storm runoff from the greater impervious surface areas and increased dry-season runoff via imported landscaping irrigation water.

Finally, some discussion of mitigation and management of physical changes was presented. Examples included land-use planning by local governments, the need to develop a better understanding of the dynamics of habitats in the face of urbanization, and a proactive effort to inform land planning and management.

5.3.4 Development-related cumulative effects to riparian ecosystems

This study presents an analysis of cumulative impacts to riparian ecosystems from the spatial distribution of development-related projects (Stein and Ambrose 2001). The development projects were authorized by USACE under Section 404 of the Clean Water Act. The Santa Margarita River watershed in Orange County, California, is part of a SAMP under the USACE Regulatory Program. Riverside County's Southwest Community Area Plan (Stein and Ambrose 2001) predicts that the population in the upper watershed will increase from a current level (in 2001) of approximately 70,000 to approximately 750,000 over the next 20 years, with an associated 245% increase in developed area. In several instances, large projects were divided into several smaller projects and permitted separately to avoid the review and mitigation requirements associated with larger-scale projects.

This piecemeal approach to permitting has resulted in incremental impacts from numerous small projects in close proximity to each other. These impacts can accumulate into adverse or substantial adverse impacts to entire stream reaches. In addition, changes have resulted in fragmentation of aquatic resources to a point where their overall functional capacity is impaired. Further, the ecological functions of unaffected areas have been diminished due to their proximity to degraded areas. The term "area" was used to illustrate the overall effects of incremental actions over time, as well as to provide a baseline for consideration of the effects of these actions on the overall stream condition. For example, 98% of the area impacted in the upper watershed was concentrated in and around urban areas that comprise only 15% of the total watershed area. Channelization of the Santa Gertrudis and Tucalota Creeks provides a clear example of the need to address the cumulative effects of physical changes resulting from piecemeal permitting.

One central theme of this case study is related to the management of cumulative impacts under the SAMP process. Accordingly, a conceptual model including management considerations was developed. Figure 7 depicts this framework for both individual permits and multiple permits within the SAMP. In this situation, cumulative effects have occurred on habitat structure, contiguity, and landscape context. The effects were quantified via the use of functional indices scaled to regional reference sites. Analysis was focused on the spatial distribution of impacts and how that distribution may have affected overall landscape scale functions of the riparian ecosystems. The assessment itself included: (1) historic analysis; (2) mapping the geology, substrate types, slopes, and land-use conditions; (3) modeling existing hydrology; (4) investigating sediment processes; (5) investigating the interaction of groundwater with surface water systems; (6) collecting baseline water quality data; (7) compiling data on the biologic resources; and (8) conducting a planning-level delineation and assessment of aquatic resources in the study area.

Several methods and technologies were used in this study. One example is the habitat-focused Rapid Impact Assessment Method (RIAM) which is based on evaluation of six criteria: endangered species habitat, structural diversity of habitats, spatial diversity and interspersion of habitats, undeveloped open space habitat, adjacent habitats (floodplain land use), and linear contiguity of habitats (Stein and Ambrose 1998). Other tools included the use of historic photographs and the location quotient (LQ) method. The LQ method was used to determine whether impacts were concentrated into certain areas of the watershed, or they were evenly distributed across the watershed. The concepts, principles and tools used would be transferable to other SAMPs within USACE Regulatory Program.

Examples of analyses and mitigation/management strategies which have been applied and will be used in the SAMP include those listed below (Stein and Ambrose 2001).

- The gross terrains of the watershed have been mapped based on substrate type and underlying geology. Development will be concentrated in areas with naturally impervious substrate types.
- Sediment yield and transport functions have been characterized. Criteria have been developed based on these data to avoid areas that may disrupt key sediment sources and to maintain natural zones of aggradation and degradation.

- The inherent erodibility of substrates has been mapped based on soil properties (e.g., k-factor), slope, underlying geology, and current land use. High intensity development and construction of roads at the top of slopes with high inherent erodibility will be avoided to the maximum extent possible.
- The timing of expected peak flows in tributary basins was compared to those in the main stem river. Increases in impervious surfaces are often associated with accelerating the time of concentration of peak flows. If this occurs in a sub-basin where peak flow lags slightly behind that of the main stem river, there is a risk in creating coincident peaks and potentially exacerbating downstream flooding or scour. By concentrating development in sub-basins where peak flow arrives at the confluence in advance of those in the main stem, this impact may be reduced.
- Intensive land-use change will occur outside the floodplain of the major creeks. Floodplains will be used for restoration or expansion of riparian zones, recreation, and/or creation of water quality wetlands and swales.
- Areas that support major populations of sensitive plant or animal species will be avoided, and streams will be utilized to maintain connectivity among these various populations.

To summarize, a general theme of this study was that a proactive approach should be used for managing cumulative impacts within a SAMP. Specifically, analysis of cumulative impacts will facilitate development that provides for protection of major wetlands and riparian areas; maintains aquatic resource functions; addresses sensitive species needs in terms of hydrology, geomorphology, and water quality; and allows for development of a comprehensive preservation, enhancement, and restoration plan for a SAMP.

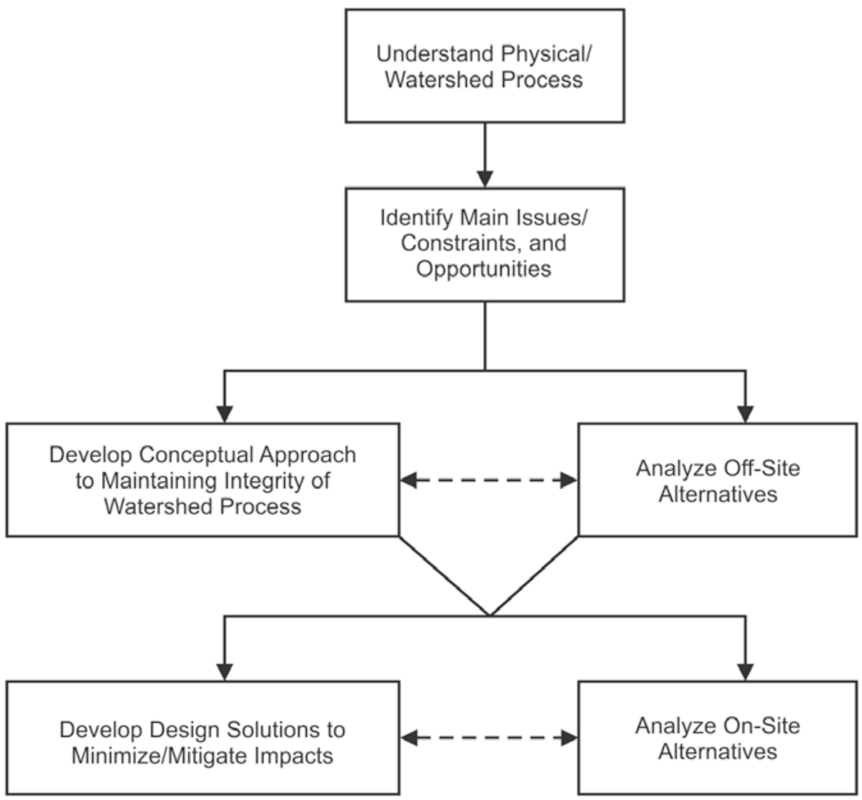
5.4 Comparative discussion of case studies

Table 3 contains summary information derived from the four case studies. To provide for consistency in the comparisons, five topics are addressed for each case: (1) features, (2) environmental effects, (3) analytical framework(s), (4) methods and technologies, and (5) mitigation and management of changes. The comparative information displayed in Table 3 reveals the points listed below.

- The study features are unique for each case.

- The addressed environmental effects are appropriate for examining experienced or potential effects from the studied physical changes.
- While the listed analytical frameworks are diverse, they each provide a relevant structure for the included scientific and policy issues.
- The identified methods and technologies are pertinent for the changes and focus of each case.
- Less direct attention was devoted to mitigation and management in these case studies; however, the effects or findings resulting from each study could be explored to further address mitigation and management of the changes of concern.

Figure 7. Approach to management of cumulative effects under the SAMP process (Stein and Ambrose 2001, 1612).



5.5 Lessons learned

Based on this review of four case studies related to land-use changes and development projects in watersheds and their associated changes on the water environment, the following lessons are noted.

- An expanding literature base is available for addressing watershed-level changes associated with land-use changes and permitted development projects.
- Mitigation and management from these types of changes should be developed from a holistic perspective—that is, a range of options and their effectiveness should be considered, along with various combinations thereof.

Table 3. Comparative information on physical changes resulting from land-use changes and development projects in watersheds.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Human and landscape interactions in a watershed (Kuczenski et al. 2000)	Examination of the relationships between land use changes and demographic indicators in the Kickapoo River watershed in southwestern Wisconsin and the use of principles of landscape ecology to discuss the implications of these changes.	Nine land-cover classes, six housing density classes, other census parameters, and potential changes in landscape ecology features	Unstated conceptual models which are based on multiple linkages between land use, demographic characteristics, and landscape ecological features	GIS, Landsat satellite imaging, selected census data, and fundamental principles of landscape ecology; the frameworks, methods and technologies would be transferrable to similar types of watersheds.	Could be developed as part of long-range planning and management efforts for the Kickapoo River watershed.
Problem formulation for a watershed ecological risk assessment (Cormier et al. 2000)	Pilot study for applying ERA as a tool for prioritizing efforts needed to protect and maintain the highly valued Big Darby Creek watershed in central Ohio.	Land use, water quality, fish and mollusks, threatened and endangered species, sedimentation, and altered hydrologic regimes	Detailed problem formulation stage framework developed by the US EPA, and an overall ERA framework (also by the US EPA)	Conceptual models for exposure of fish and benthic macroinvertebrates, surveys of fish and mollusks, several biological indices, modified index of well-being, comprehensive literature reviews, and assessment endpoints	Not addressed; however, could be considered under the risk analysis, characterization, and management phases of ERA.
Watershed urbanization effects on streamflow characteristics and riparian vegetation (White and Greer 2006)	Study of watershed urbanization in the Penasquitos Creek watershed in Southern California, and the consequential changes on stream hydrology and riparian vegetation.	Runoff, streamflow, flooding, and riparian vegetation communities	No specific framework was used; however, the study was well planned and scientifically defensible.	Aerial images and photographs of land uses and riparian vegetation communities, land use mapping and GIS; regression analyses and ANOVA	Land-use planning by local governments, education on changes on habitat dynamics, and public information dissemination
Development-related cumulative effects to riparian ecosystems (Stein and Ambrose, 2001)	Analysis of cumulative incremental effects of Clean Water Act Section 404 permits in the Santa Margarita watershed in Orange County, California	Effects on riparian habitat structure and contiguity, landscape context, water quality, sedimentation, and aquatic resources.	Conceptual model as shown in Figure 7	Habitat-focused RIAM, historic photographs, location quotient for impacts, land use mapping and GIS, flow measurements and predictions, and geological mapping	Some examples were identified for inclusion in the Special Area Management Plan (e.g., siting, protected areas, and re-connecting riparian and aquatic zones).

6 Physical, Social, and Institutional Changes Associated with Land Use and Related Policy Changes in River Basins

6.1 Introduction

This chapter summarizes three case studies related to PSI changes resulting from land use and related policy changes in river basins. Such land use and policy changes can alter surface water runoff, groundwater recharge, and water and sediment quality in nearby streams, rivers, and lakes. Accordingly, water resources planning studies, including those for specific projects, should account for historical, current, and even future land use and policy changes within river basins and their designated project or plan areas.

Section 6.2 presents the case order. In Section 6.3, Subsections 6.3.1–6.3.3 summarize the three cases by presenting information on each case derived from using the review form in Appendix A. Section 6.4 contains a comparative discussion of the key findings from each case. Finally, several overall lessons are highlighted in Section 6.5.

6.2 Order of case studies

The three case studies summarized in this chapter are presented in the order listed below.

1. Strategic restoration of wetlands in a river basin - reducing consequential changes from degraded wetlands (White and Fennessy 2005)
2. Irrigation and dryland development impacts on river base flows and salt loads (Knight et al. 2005)
3. Planning for long-term sustainability within a river basin (Rideout et al. 2005).

These three case studies are related to PSI changes over time that has occurred at a river-basin scale. Further, each case emphasizes planning and management activities which could be used to reduce undesirable consequential changes to their associated water resources. The first case focuses on strategic planning for restoring degraded wetlands in the Cuyahoga

River Basin in northeastern Ohio (White and Fennessy 2005). A systematic suitability model was developed and applied to the prioritization of restoration projects. The second case addresses long-term changes in the base flows and salt loads in the Murray River Basin in South Australia. These consequential changes result from decades of physical changes in irrigated agricultural developments and other dryland developments in the basin (Knight et al. 2005). An analytical model was used to calculate time-related and location-related water balances, river water withdrawal, groundwater recharges and groundwater discharges.

The third case is focused on a planning study for information needed to determine historical to current to future sustainability in the Connecticut River Basin in New England (Rideout et al. 2005). This study involved scientific evaluations and wide-scale stakeholder collaboration. It provides a good foundation which could be used for planning studies in other basins.

6.3 Description of case studies

Following are summary descriptions of each of the three case studies addressed. The common thread across all cases involves the environmental and water resources consequences resulting from land use and policy PSI changes at the river-basin level.

6.3.1 Strategic restoration of wetlands in a river basin — reducing consequential changes from degraded wetlands

This case study addresses suitability modeling for determining wetland restoration potential in the Cuyahoga River Basin in northeastern Ohio (White and Fennessy 2005). The fundamental concept is that wetlands which have been subject to physical changes over time within a basin can be systematically evaluated in order to determine their restoration capacity and ability to achieve and maintain the water resource integrity of the basin. Accordingly, the focus is on restoring wetland resources which have been impacted by physical changes. Prioritization of such wetlands should yield an overall strategy which could be integrated within established restoration goals.

A wetland restoration suitability model was developed to serve as an integrating tool for the study. Fundamentally, a weighted multi-criteria model was utilized. The site-related general criteria included: (a) physical parameters (hydrologic regime, vegetative character, soil character, and topogra-

phy) and (b) wetland functions parameters (overland flow distance from wetland grid cell to the nearest perennial stream, the extent to which aquatic life-use standards are met in adjacent streams, and the Strahler stream order). Numerical information for interpreting the score for each criterion was also developed. Relative importance weighting for these criteria were assigned by selected subject matter experts via use of the paired-comparison approach developed by Saaty (1977). The sum of the product of each criterion score for a site multiplied by its relative importance weight yielded an overall score for each wetland. Details on specific criteria, their evaluation, and their associated importance weight are described by White and Fennessy (2007).

The analytical framework consisted of a two-phase approach. The first phase was to develop criteria, or environmental indicators, to identify the total population of sites suitable for wetland restoration. The second phase "filtered" the total population of available sites in order to prioritize them according to their potential to contribute to water resource integrity once restored. In that sense, the purpose of this study was to develop a watershed-level, site-suitability model using a GIS to assess the potential for wetland restoration in the Cuyahoga River Basin. The modeling approach was also designed to identify the spatial distribution of sites most suited to wetland restoration.

The methods and technologies used included a GIS-based model to predict the suitability for wetland restoration. Criteria used by the model included spatial location, hydric soils, land use, topography, stream order, and a saturation index based on slope and flow accumulation in each grid cell in the model. Two scales were used for the model; the first scale consisted of physical parameters that best define wetland properties or form, while the second scale consisted of those parameters that best characterize wetland functions. Additional tools which were used included Landsat Thematic Mapper imagery, the TOPMODEL hydrologic model* (also described in Beven and Kirkby 1979), sensitivity analyses, and an effectiveness matrix.

* A topography-based hydrological model created by Keith Beven of CSDMS: Community Surface Dynamics Modeling System, University of Colorado, Boulder, CO. TOPMODEL is a physically based, distributed watershed model that simulates hydrologic fluxes of water (infiltration-excess overland flow, saturation overland flow, infiltration, exfiltration, subsurface flow, evapotranspiration, and channel routing) through a watershed. The model simulates explicit groundwater/surface- water interactions by predicting the movement of the water table, which determines where saturated land-surface areas develop and have the potential to produce saturation overland flow.

The principles and concepts related to these methods are transferable and provide a useful and practical method for identifying and prioritizing among potential wetland restoration sites at a river-basin level.

6.3.2 Irrigation and dryland development impacts on river base flows and salt loads

This case study was focused on the development of regional quantitative models to address both the timing and quantities of experienced and anticipated cumulative impacts on base flows and salt loads in the Murray River Basin in South Australia (Knight et al. 2005). This major basin has been subjected to physical changes in the patterns of river water usage—specifically, increases in irrigated agricultural developments as well as other water usage related to dryland developments. These increases over the last century have become of more recent concern due to their resultant increases in base flows, river salinities, and salt loads. Numerous concerns have arisen over the long-term cumulative consequences of these patterns. While this case study is focused on changes in river flows and salinities, additional issues include detrimental consequences to aquatic ecosystems, habitats, and interdependent riparian and aquatic species.

To provide an illustration of changes in the Murray River Basin, the natural salt loading under predevelopment conditions was about 900,000 kg per day. Historical to current increases in basin-wide irrigation and dryland development has raised the salt loading to 1,400,000 kg per day (a 64% increase). Still further increases would be anticipated with future developments and greater water demands. In addition, a more immediate concern is that the major city of Adelaide is located in the lower part of the basin and relies heavily on the Murray River for its water supply (Knight et al. 2005).

In view of these concerns, it was decided that an analytical approach involving water balances, spatial locations, river water withdrawals, groundwater recharge, and groundwater discharges would be utilized. The modeling approach would be useful for estimating the timing of the groundwater response to changes in recharge, and the effect of these changes on groundwater discharge to a river. Thus, the model could be used for assessing management implications of new irrigating developments, groundwater pumping schemes, and revegetation strategies based on stream flow (and hence on the stream salt load) (Knight et al. 2005).

A two-dimensional linearized Boussinesq equation was used to develop a one-dimensional unit response function for a change in recharge to an aquifer; this function was then used to project changes in groundwater discharge to the river. The paper itself contained a considerable amount of theoretical and derivation-related discussion of the modeling; although the mathematics of the modeling are complex, the concepts are simple to understand. The Boussinesq equation and related regional base flow and salt load models could be adapted to other locations.

Finally, although there was no specific discussion of the mitigation and/or management of the changes, the modeling results could be used to develop location-specific strategies to mitigate the negative features of increases in base flows and salt loads.

6.3.3 Planning for long-term sustainability within a river basin

This case study involved the development of a science-based framework for evaluating historical to current sustainability conditions within the Connecticut River Basin in New England (Rideout et al. 2005). The river's watershed encompasses parts of four states (Vermont, New Hampshire, Massachusetts, and Connecticut); further, the river supplies water to several major urban centers (Boston, Worcester, Springfield, and Hartford), numerous small towns, and many rural residents (through groundwater). Several major tributaries of the Connecticut River have been identified by state agencies as "hydrologically stressed basins," including the Farmington Basin and portions of the Deerfield Basin. For example, when summertime low flows occur then stress is increased on aquatic habitats.

The study itself involved cooperation between the US Geological Survey, the US Fish and Wildlife Service, and the University of Massachusetts at Amherst. In addition, federal, state, and local agencies participated including USACE. Several consulting firms and nongovernmental organizations were also involved. In fact, a 70-person steering committee was formed and played a major role in planning to achieve long-term sustainability within the basin.

An integrating feature of this study involved the adoption of the following working definition of sustainability (adapted from Meffe et al. 2003):

> The term "sustainability" encompasses a certain set of long-term goals to maintain healthy ecosystems and the human communities that depend

> on them; it focuses particularly on how people maintain or restore the composition, structure, and function of natural and modified ecosystems to meet the needs of current and future generations. It is based on a collaboratively developed vision of desired future conditions that integrates ecological, socio-economic, and institutional components, applied within a geographic framework defined primarily by natural ecological boundaries.

The following list contains some of the reasons that the Connecticut River Basin (watershed) was chosen for this case study (Rideout et al. 2005).

- Land-use changes in New England could dramatically alter the character of the landscape, with large implications for natural resources and ecosystem services. The basin already has a gradient of human pressure that increases from the north (relatively undeveloped) to south (significantly modified by human presence).
- The Connecticut River Basin has a long history of native forests being converted to agricultural lands and later returning back to forest.
- The complex institutional arrangements that arise from four states and almost 400 towns sharing the watershed provide an opportunity to conduct joint planning for the common good.
- Multiple types of land uses occur, and there are numerous dams in the basin including 14 operated by USACE.
- Many active and long-standing institutional partnerships exist, although there is room for better coordination.

Through the study process, 14 science issues were identified and addressed in association with three questions: (1) Where are we now?, (2) Where are we going?, and (3) How will we get there (within a target study period to 2050)?

The following issues were included in those addressed when answering the first question.

- water budgets, allocations, and water used (historical to current)
- water-quality issues for both surface water and groundwater (nutrient concerns, total maximum daily load (TMDL) strategies, combined sewer overflows (CSOs), agricultural BMPs, sediment transport, and pollution from polychlorinated biphenyls (PCBs) and fish consumption advisories.

- need for situational assessment of numerous smaller and larger dams in the Basin (an estimate is a total of about 980 dams).
- biogeochemical cycling — chemical cycling and the transport and fate of contaminants are important issues to understand in order to predict the long-term environmental changes; needed research on chemical cycling includes understanding the sources and pathways of nitrogen, phosphorus, PCBs, etc. in the watershed system
- socioeconomic issues and economic benefits of sustainability within the Connecticut River Basin
- need for a current “State of the Watershed (Basin) Atlas”

Issues associated with the second question (“Where are we going?”) involve consideration of desired future conditions within the basin. The following list includes examples of issues to be addressed when answering the second question (Rideout et al. 2005):

- developing a shared public vision among multiple stakeholders
- addressing the need for and value of achieving and maintaining environmental flows including actual location information for recommended flows
- defining relationships between land-use changes and resultant losses of terrestrial habitat and impacts on the associated mammals, bird, reptiles, and plants—including threatened, endangered, or protected species—and establishing useable databases which could be utilized by all interested stakeholders.

The following list contains included issues that are related to the third question (How will we get there?) (Rideout et al. 2005).

- Projecting future land uses and populations within the basin—this projection would entail the development of land-use and land-cover change models, consideration of the use of build-out analyses and scenarios (alternative futures), and development of simulation models that can link landscape change to changes in hydrology, water-quality conditions, sediment transport, ecosystem changes, and the influence of invasives. Further, capabilities within GIS mapping should be expanded, with such mapping being connected to flow models and the goal being the ability to conduct evaluations of different scenarios and management strategies.

- Integration of management and operational practices for 14 USACE flood-control dams on tributaries and 16 main stem hydropower dams operated by the private sector. Such integration should be built on historical to current information on these dams, their operational practices, and associated legal or regulatory constraints.
- Assessment of the economic and environmental benefits, goods, and services provided by the key dams and development of decision-support tools tailored for the evaluation of how each dam affects the flow regime and contributes to habitat fragmentation, and to identify which of them are likely to become maintenance hazards in the next few decades.
- Development and utilization of an encompassing land usage and environmental data-sharing system for governmental entities and other key stakeholders.
- Conduction of periodic institutional and policy analyses in order to keep the basin information both up-to-date and focused on the future.

In addition, the broad planning study was used to identify five priority issues which could be undertaken in the near term, as listed below.

1. *Water budgets and allocations* (e.g., develop basin models, prepare information on system descriptions and operations, and delineate flow impacts associated with dam removal)
2. *Water quality* (e.g., TMDL models, CSO impact analysis, sediment transport, and sediments with legacy contaminants)
3. *Ecological flow prescription* (e.g., required flows to sustain biodiversity, flows associated with target fish communities, and flows necessary for fish passage)
4. *Development of data-sharing systems* (e.g., web-based GIS systems, Watershed Atlas)
5. *Development of a shared public vision* for the watershed

Finally, this broad planning study could be used as a comprehensive framework to address sustainability needs in numerous river basins and watersheds. The interactive methodologies, broad perspectives, and collaboration regarding the future would be applicable across all studies of this nature.

6.4 Comparative discussion of case studies

Table 4 contains summary information derived from the three case studies. To provide for consistency in the comparisons, five topics are addressed for each case: (1) features, (2) environmental effects, (3) analytical framework(s), (4) methods and technologies, and (5) mitigation and management of changes. The comparative information displayed in Table 4 reveals that the points listed below.

- The specific study features are unique for each case.
- The environmental effects addressed are appropriate for examining experienced or potential effects from the studied causative changes in land use and policies.
- While the listed analytical frameworks are diverse, they each are scientifically defensible and consistent with similar types of studies.
- The methods and technologies identified are wide-ranging; however, they are pertinent for the causative and consequential changes and focus of each case, and they are transferrable to other similar PSI change related studies.
- The types of tools routinely included: land use information, GIS, indicators and indices, and simple-to-sophisticated mathematical models.
- None of the three cases devoted major attention to mitigation and management; however, upon completion of the specific studies, it would be useful to explore relevant options.

6.5 Lessons learned

Based on this review of three case studies that are related to land use and policy changes at the river-basin level, the following lessons are noted.

- A growing literature base is available for addressing river basin-level land-use physical changes and policies, and their local to basin-wide consequences on runoff, stream flows, groundwater systems, water quality, and aquatic ecosystems.
- River basin planning can provide spatial boundaries which are appropriate for addressing future causative changes and consequential changes; scenario analyses involving alternative futures can be a useful tool for bounding these issues.

Mitigation and management of changes should be developed from a holistic perspective — a range of options, combinations, and their effectiveness should be considered.

Table 4. Comparative information on physical, social, and institutional changes resulting from land-use and related policy changes in river basins.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Strategic restoration of wetlands in a river basin – reducing consequential changes from degraded wetlands (White and Fennessy 2005)	A suitability model and prioritization scheme for determining the restoration potential of degraded wetlands in the Cuyahoga River Basin in northeastern Ohio	Use of indicators to reflect wetland functions; examples include spatial location, hydric soils, topography, adjacent land uses, and order of nearby streams.	A wetland restoration suitability model comprised of multiple weighted indicators	GIS, selected indicators, Landsat Thematic Capper imaging, and the TOPMODEL (hydrologic model)	Restoration of high priority degraded wetlands would lessen the cumulative impacts of changes on such wetlands.
Irrigation and dryland development impacts on river base flows and salt loads (Knight et al. 2005)	Regional modeling to address timing and quantification of changes to base flows and salt loads in the Murray River Basin in South Australia; these changes have been caused by large-scale agricultural irrigation and dryland development projects.	Locational base flows, salinities, and salt loads in the Murray River	Combined consideration of water balances, spatial locations, river water withdrawals, groundwater recharge, and groundwater discharges	Two-dimensional linearized Boussinesq equation for calculating changes in recharge to an aquifer and regional flow and salt load models	No specific discussion included; however, modeling would aid in the evaluation of location-specific strategies to increase base flows and reduce salt loads.
Planning for long-term sustainability within a river basin (Rideout et al. 2005)	Development of a science-based framework for evaluating sustainability conditions within the Connecticut River Basin in New England.	Land-use change effects on ecosystem services, changes in native forested lands, water quality associated with surface and groundwater, biogeochemical cycling, environmental flows, and terrestrial and aquatic habitat and species	Broad issues associated with river basin planning	Land-use/land-cover change models, build-out scenarios, simulation models for linking land-use changes to water quality and aquatic ecology, and GIS	Upon completion, study results would aid the identification and mitigation of changes.

7 Physical, Social, and Institutional Changes Associated with Land Uses and Related Policy Changes in River Basins: A Comprehensive Study for the Willamette River Basin in Oregon

7.1 Introduction

This chapter summarizes six interrelated case studies which addressed PSI changes resulting from land use and policy changes, to the year 2050, in the Willamette River Basin in Oregon. Such changes can alter water use, agriculturally related land uses, wildlife, water rights and allocations, and fish and invertebrates within basin streams. Scenario analysis was an integrating theme across the six cases. Accordingly, river basin planning studies—including those for specific projects therein—should account for future causative changes and their consequential effects.

Section 7.2 presents the case order. In Section 7.3, Subsections 7.3.1–7.3.6 summarize the six addressed cases by presenting summary information on each case derived from using the review form in Appendix A. Section 7.4 contains a comparative discussion of the key findings from each case. Finally, several overall lessons are highlighted in Section7.5.

7.2 Order of case studies

The six interrelated case studies summarized in this chapter are presented in the order listed below.

1. Overview of Willamette River Basin study (Baker et al. 2004)
2. Foundational study — citizen guidance for scenario building (Hulse et al. 2004)
3. Foundational study — evaluation of policy options on agricultural landscapes (Berger and Bolte 2004)
4. Foundational study — wildlife responses to landscape and vegetation changes (Schumaker et al. 2004)
5. Foundational study — water allocations and in-stream environmental flows (Dole and Niemi 2004)

6. Foundational study — use of indicators in assessing biological conditions of streams (Van Sickle et al. 2004).

The first case study by Baker et al. (2004) contains summary information on the scope of the basin study as well as its general findings. The next five cases represent foundational studies within the overall basin study. The first foundational study addresses citizen input and guidance in developing three alternative futures (scenarios) to 2050, and in mapping future land and water use in the basin (Hulse et al. 2004). The second foundational study describes the use of scenarios for evaluating future growth patterns and resultant resource allocations on the agricultural system (Berger and Bolte 2004). Projections of wildlife responses to the three scenarios presented by Hulse et al. (2004) are addressed in the third foundational study, along with species-habitat relationships which were used in the projections and evaluations (Schumaker et al. 2004). The fourth foundational study focuses on water uses, rights, and allocations, along with water conservation to protect in-stream ecological values for the three scenarios (Dole and Niemi 2004). Finally, Van Sickle et al. (2004) describe the use of regression models to forecast the biological condition of fish and invertebrates in streams within the Willamette River Basin. These forecasts were made for the three planning scenarios to 2050 (from Hulse et al. 2004) and the forecasts were based on physiographic, land-use/land-cover, and selected stream-flow variables.

Detailed information is included from the Baker et al. (2004) case study. Brief summary information is then presented for the five foundational studies. For planning specific river-basin studies elsewhere, it is suggested that each of the six papers addressed be carefully reviewed, along with their related technical reports.

7.3 Description of case studies

Following are summary descriptions of each of the six case studies. The common thread across all six cases involves changes in land use and policies and their environmental and water resources consequences.

7.3.1 Overview of Willamette River Basin Study

A comprehensive, wide-ranging, and long-term planning study for the Willamette River Basin (WRB) in western Oregon was conducted in the early 2000s. The WRB encompasses 29,728 km^2 between the Cascade

Range and Coast Range mountains. Within the valley area of the WRB, approximately 43% of the land is in agricultural use (Baker et al. 2004). The three largest cities in Oregon (Portland, Salem, and Eugene-Spring field) are located in the WRB and are adjacent to the river. The 1990 population in the WRB totaled about two million people. By 2050, the population is expected to increase to 3.9 million persons.

The citizens and state government of Oregon have long exhibited interests in the environmental, economic, and social sustainability of the WRB. In fact, in 1996 a stakeholder group entitled the Willamette Valley Livability Forum (WVLF) was created, and in 1998 the Willamette Restoration Initiative (WRI) was formed. These groups were actively involved in the WRB study.

The temporal boundaries for the study encompassed a 200-yr period. The historical initiating point was about 1850, a time referred to as pre-EuroAmerican settlement. A historical land-use/land-cover map was assembled for this period; it included information on pre-settlement vegetation and classifications, forest lands and types of forest, and general types of land-use/land-cover information (Baker et al. 2004). “Current” conditions in the basin were reflected by data and information from about 1990. The assembled information included land-use/land-cover data from Landsat as displayed via GIS. Other information related to soils data, irrigation records, crop statistics and agricultural classes, land ownership, 1990 US Census data, zoning classifications, topographic features, and infrastructure locations (e.g., roads and highways).

The year 2050 was chosen as the future planning horizon for the WRB study. However, rather than single projections of conditions to 2050, it was determined that three alternative futures (scenarios) would be defined and evaluated. As noted in earlier chapters of this report, the use of “scenario analyses” as a tool in water resources planning and related impact studies has been increasing (Duinker and Greig 2007).

The three alternative futures for the WRB are referred to as Plan Trend 2050, Development 2050, and Conservation 2050. Their definitions are outlined below (Baker et al. 2004).

- **Plan Trend 2050** – represents the expected future landscape if current conservation and development policies are implemented exactly as

written, and if recent trends in population growth and water usage continue.
- **Development 2050** – reflects a loosening of current policies to allow freer rein to be given to market forces across all components of the landscape, but still within the plausible range as considered by the stakeholder groups.
- **Conservation 2050** – places greater emphasis on ecosystem protection and restoration, although still reflecting a plausible balance among ecological, social, and economic considerations as defined by the stakeholders.

It should be noted that all three of the above scenarios assume that the 2050 WRB population will be 3.9 million people. More details about the three scenarios are contained in Hulse et al. (2004) and Berger and Bolte (2004). The WRB study then evaluated the likely effects of the three scenarios on changes associated with land uses and landscape, and the consequences on four endpoints of concern as noted below (Baker et al. 2004).

- *Water availability* – demands for surface water for irrigation, municipal and industrial processes, fish protection, and other uses, and the degree to which these demands can be satisfied by the finite water supply in the basin (Dole and Niemi 2004).
- *Willamette River* – channel structure, streamside vegetation, and fish community richness in the mainstem of the Willamette River (Van Sickle et al., 2004).
- *Ecological condition of streams* – habitat and biological communities (fish and benthic invertebrates) in all second-order to fourth-order streams in the basin (Dole and Niemi 2004; Van Sickle et al. 2004).
- *Terrestrial wildlife* – habitat for amphibians, reptiles, birds, and mammals in the basin, and the abundance and distribution of selected birds and mammals (Schumaker et al. 2004).

Summary information from each of the above-listed studies will be presented in subsequent subsections.

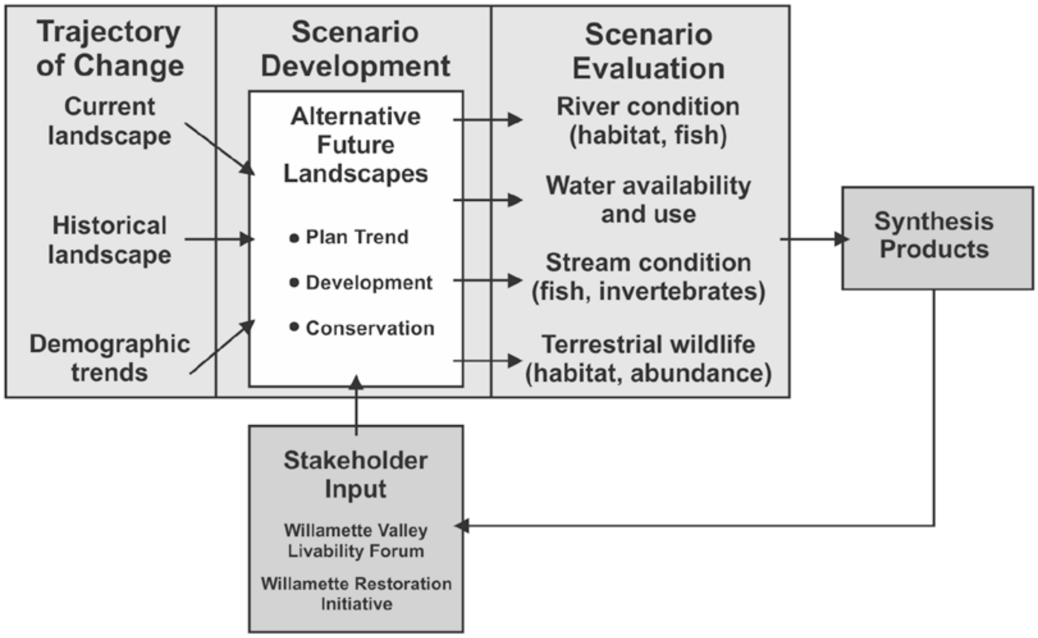
Figure 8 displays the general analytical framework used in the WRB study (Baker et al. 2004). The trajectory of change reflects historical to current conditions. The three future scenarios were used along with the evaluation of their consequences on the above four endpoints of concern. Stakeholder

input is also identified along with providing feedback on various written products that were generated.

Indicators were chosen to reflect changes in the four endpoints noted above and are explained below (Baker et al. 2004).

- *Indicators of human use* included: mean human population density within urban growth boundaries (UGB); total area affected by urban development, by rural development, and by urban and rural development combined; area of prime farmland; and quantity of water consumed for out-of-stream uses.
- *Indicators of natural resource conditions* in the WRB study included vegetation indicators comprised of the estimated area of conifer forests more than 80 yr old and percentage of 120-m wide riparian buffer along all streams in the Valley Ecoregion with forest vegetation.
- The *indicator for native terrestrial wildlife habitat* was the percentage of 256 native non-fish vertebrate species projected to gain habitat minus the percentage projected to lose habitat.
- The *indicator of terrestrial wildlife abundance* was the percentage of 17 species modeled and projected to increase more than 10% minus the percentage projected to decline more than 10%.
- *Stream condition indicators* included the percentage change in the median cutthroat trout habitat suitability index (HSI) for all second-order to fourth-order streams in the basin, and the percentage change in median fish IBI and Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness in second- to fourth-order streams with watersheds predominately in the Valley Ecoregion.
- The *Willamette River indicator* was the percentage change in median fish richness.

Figure 8. Diagram of alternative futures analysis process applied in the Willamette River Basin Study (Baker et al. 2004, 315).



Several types of models were used for addressing the four categories of resources. For example:

> "… water availability was assessed using a computer model ('The Watermaster') simulating the allocation of water among competing uses. An individual-based, spatially explicit, population model (PATCH: Program to Assist in Tracking Critical Habitat) simulated changes in wildlife abundance and distribution. Regression models, based on extensive survey data, were used to estimate biotic changes in streams and the river. Habitat suitability indices for both streams and wildlife were derived from expert-defined rules. Willamette River channel complexity and streamside vegetation, although listed above, were more closely aligned with scenario development than evaluation. Detailed reconstructions of the river channel and adjacent vegetation were created for 1850, 1895, 1932, and 1990 based on available data. These maps, together with stakeholder-defined targets and constraints, were used to identify areas of the river most likely to lose (Development 2050) or recover (Conservation 2050) channel complexity in the future." (Baker et al. 2004, 316)

The spectrum of modeling approaches noted above was used to determine percentage changes between an indicator baseline condition and the projected condition in 2050. For human use indicators, the percentage changes for the three scenarios were reflected relative to 1990 conditions. The projected natural resource indicators were also compared to the 1990 conditions. Further, percentage changes in the historical conditions, along with the three 2050 conditions were presented. Figure 9 and Figure 10 display the composited results for human use and natural resource indicators, respectively (Baker et al. 2004).

Figure 9. Projected changes in selected indicators of human use in the WRB Study (Baker et al. 2004, 317).

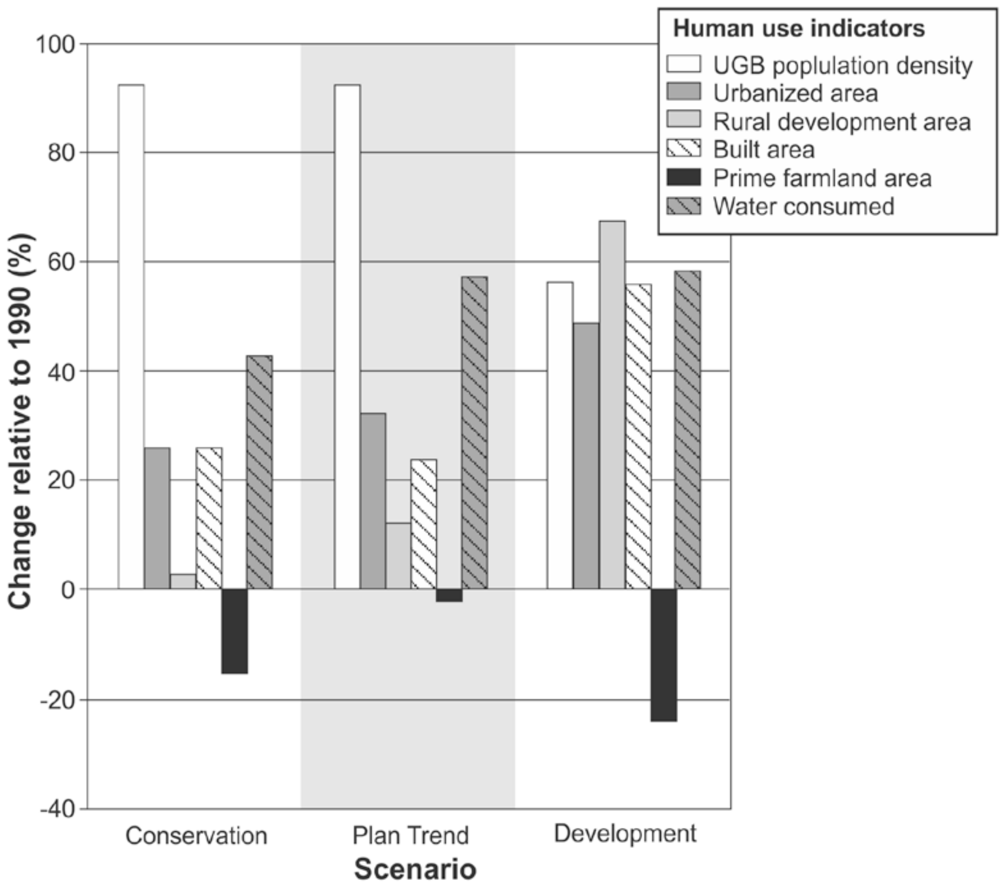
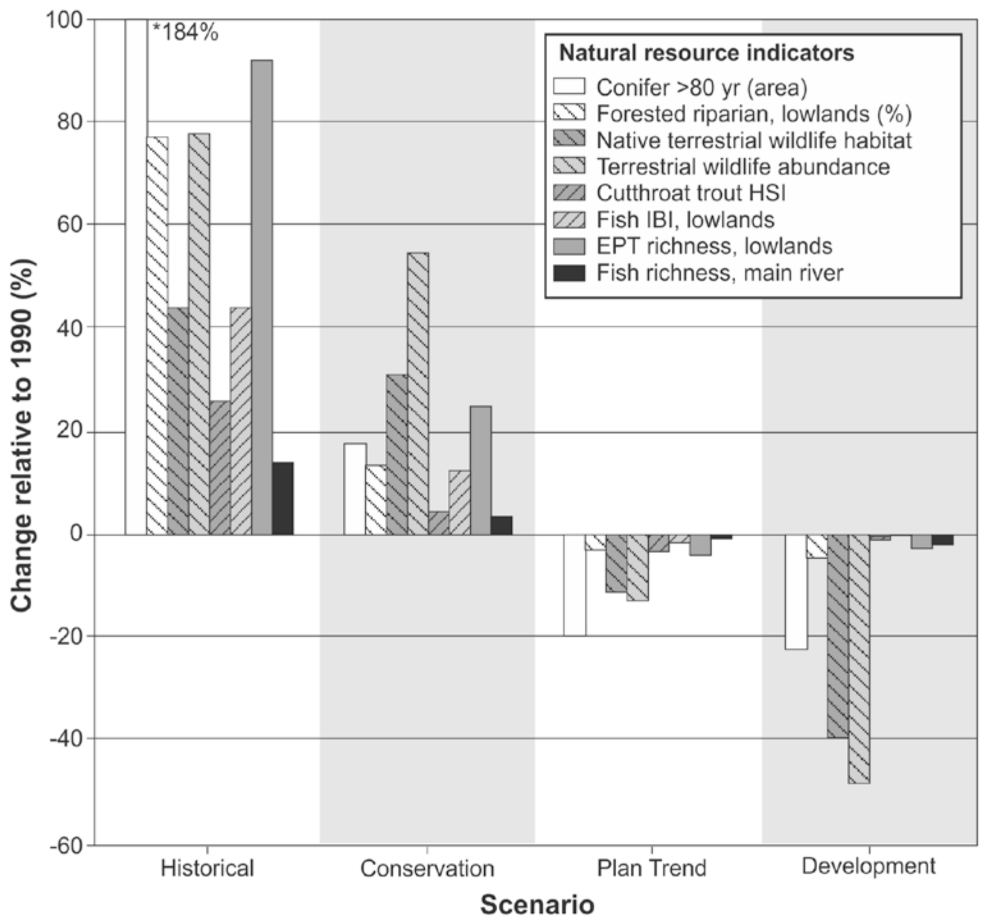


Figure 10. Projected changes in selected indicators of natural resources (Baker et al. 2004, 318).



The general findings of this study are concisely summarized below (Baker et al. 2004, 313).

> "The Plan Trend 2050 scenario assumes current policies and trends continue. Because Oregon has several conservation -oriented policies in place, landscape changes and projected environmental effects associated with this scenario were surprisingly small (most ≤10% change relative to 1990). The scenario did, however, engender a debate among stakeholders about the reasonableness of assuming that existing policies would be implemented exactly as written if no further policy actions were taken. The Development 2050 scenario reflects a loosening of current policies, and a more market-oriented approach, as proposed by some stakeholders. Estimated effects of this scenario include loss of 24% of prime farmland; and 39% more wildlife species would lose habitat than gain habitat relative to the 1990 landscape. Projected effects on aquatic biota were less

> severe, primarily because many of the land use changes involved conversion of agricultural lands into urban or rural development, both of which adversely impact streams. Finally, Conservation 2050 assumes that ecosystem protection and restoration are given higher priority, although still within the bounds of what stakeholders considered plausible. In response, most ecological indicators (both terrestrial and aquatic) recovered 20-70% of the losses sustained since Euro-American settlement. The one exception is water availability. Water consumed for out-of-stream uses increased under all three future scenarios (by 40-60%), with accompanying decreases in stream flow."

These findings continue to be used by stakeholder groups and governmental agencies in developing a vision for the basin's future and in planning a basin-wide restoration and recovery strategy.

To summarize selected features of the WRB study, the analytical framework was conceptually sound and scientifically defensible. Further, the use of methods and technologies such as mapping and GIS, selected indicators of human use and natural resources, various types of conceptual and mathematical models, and policy analyses were reasonable and consistent within the professional practice of river-basin studies. Also, the principles and concepts associated with the framework and the various tools are transferable to other river-basin studies. Finally, it should be noted that information on mitigation and management was embedded in the three scenarios.

7.3.2 Foundational study — citizen guidance for scenario building

This case study describes how citizen guidance (from both lay and professional citizen groups) was sought with regard to delineating the three policy-based scenarios (Plan Trend 2050, Development 2050, and Conservation 2050) for the WRB studies (Hulse et al. 2004). Further, the citizen guidance was used in mapping future land and water use. Particular attention was given to the Conservation 2050 scenario. Specifically, they study states that greater emphasis was devoted to ecosystem protection and restoration, while still

> "… reflecting a plausible balance among ecological, social, and economic considerations as defined by the stakeholders. For the Conservation scenario, natural resource managers and scientists provided estimates for the area of key habitats required to sustain, in perpetuity, the array of

> dependent species. Spatially explicit analyses identified locations biophysically suited to meet the area targets. These locations, titled the Conservation and Restoration Opportunity Area, were mapped and then reviewed by a series of groups regarding the political plausibility of conserving or restoring them to the indicated vegetation types. The three alternative 2050 futures, as well as the 1850 past conditions, were then evaluated by an array of evaluation models described for the other four foundational studies. The Conservation and Restoration Opportunities map from the Conservation 2050 scenario was adopted by the group charged with salmon recovery in the basin as the centerpiece of its restoration strategy." (Hulse et al. 2004, 325)

The analytical framework used for this foundation study was logical, scientifically based, and analytical. The methods and technologies utilized included land-use delineations and GIS mapping, collaborative planning, historical data and trends analyses and projections, and policy analyses. Regarding mitigation and management, particular attention was given to habitat conservation and restoration opportunities in the Conservation 2050 scenario.

7.3.3 Foundational study — evaluation of policy options on agricultural landscapes

This case study was focused on identifying and evaluating the physical changes and impacts of the three scenarios on agricultural land cover and use in the WRB study (Berger and Bolte 2004). The effects of such changes were addressed in terms of farmland conversion, crop distribution, soil erosion, groundwater vulnerability, riparian land cover, and wildlife habitat quality. The summary of findings from this case (Berger and Bolte 2004, 342) noted that modeling of the three scenarios:

> "…first required the development of a spatial representation of the current agricultural system. Next, rules and constraints based on the three policy scenarios were formulated. Then a spatially explicit, multi-attribute, decision-making model was used to model changes in agricultural land cover and land use. This procedure generated three future landscapes, each depicting an alternative state of the agricultural system in the year 2050. Finally, the agronomic and environmental condition of each agricultural system was evaluated by using landscape metrics and screening models. The results show that the type and amount of farmland conversion were the scenario elements that most distinguished the

> future agricultural landscapes. By continuing current land use policies, nearly all of the existing farmland was conserved for future agricultural use, while both the market-driven and environmental restoration scenarios converted 15% or more of the agricultural land to other uses. The use of farmland for vegetation restoration activities was particularly successful in improving riparian habitat, while habitat quality over the region showed widespread improvement. The patterns of crop selection in each future followed general trends, but with variations among scenarios as crop selection decisions adapted to changing field and basin conditions."

The analytical framework used for this foundation study was built around the decision model noted above. The model and approaches used were logical, scientifically based, and analytical. The methods and technologies utilized included agricultural land uses and GIS, an agricultural landscape-evolution model, a decision model for crop selection, several agricultural-related indicators, the Universal Soil Loss Equation, groundwater vulnerability potential, and policy analyses. The concepts and principles associated with these tools would be transferable to other river-basin studies involving agricultural land uses. Finally, mitigation and management of PSI changes was embedded in the scenario analyses.

7.3.4 Foundational study — wildlife responses to landscape and vegetation changes

One important measure of the quality of a landscape is its capacity to support viable populations of a variety of wildlife species. This foundational study used two recent multi-species landscape-level assessment models to evaluate WRB wildlife responses to landscape and vegetation changes associated with the three 2050 scenarios (Schumaker et al. 2004). The simpler of the two models was based on descriptive statistics applied to an entire fauna. The more complex assessment used an individual-based model to carefully examine a subset of this fauna. Both models rely on species-habitat relationships. Accordingly, GIS maps of pre-European settlement, 1990 habitat conditions, and projections to 2050 were used for the three scenarios.

The following excerpt summarizes the key findings from this foundational study.

> "Our simpler assessment generated statistics of landscape change from the GIS imagery and species-habitat relationships for all 279 amphibian,

> reptile, bird, and mammal species in the Basin. Our more complex assessment used an individual-based life history simulator to estimate population sizes for a small subset of this fauna. These two assessments offer complementary kinds of information about wildlife responses to landscape change: estimates of habitat changes for a large number of species representing a region's biodiversity, and estimates of changes in the persistence of populations of key species. We found both good and poor correlations between our two assessments, depending upon the species and landscape. Both assessments agreed in their overall ranking of the landscapes' quality for wildlife. In most cases, the percentage change in habitat quality under- estimated the percentage change in population size. In a few cases, small gains in habitat quality were accompanied by very large increases in wildlife populations. We attribute discrepancies in our two assessments to the influence habitat fragmentation had on our individual-based model. As such, our study provides a methodology for separating the influences of habitat quality and quantity from those of habitat pattern." (Schumaker et al. 2004, 381)

The analytical frameworks used in this case included both the simpler and more complex assessment models. The PATCH model was the simpler model, and the SEPM (Spatially Explicit Population Model) was the more complex. Other methods and technologies used included Landsat imagery, GIS, species-habitat models, and literature reviews. Further, expert panels were used to develop wildlife habitat-species relationships for each of the 279 species in the WRB. The concepts and principles of the frameworks and tools are transferable to other river-basin studies. Finally, mitigation and management considerations were embedded in the scenario analyses.

7.3.5 Foundational lows

This case study was focused on the impacts of the three 2050 scenarios on surface water resources in the WRB. Water rights within the WRB are based on a system of law that integrates all water rights in a potentially complex web of interactions. Accordingly, the rights were analyzed using a basin-wide approach in which simulations were generated of the allocation of surface water across all water rights in the entire basin (Dole and Niemi 2004). Two issues were addressed within the analyses—namely, (1) the impact of increased urban demand for water and (2) protecting ecological values through an existing program to conserve water and devote the savings to in-stream water rights. The latter represented what key stakeholders in the WRB felt was the greatest environmental protection that was

politically feasible. In addition, interest in "environmental flows" to improve water quality, enhance populations of threatened and endangered aquatic species, and restore natural riverine functions was also addressed.

The Watermaster (an Oregon water rights and water allocation model) was the primary method utilized. In fact, it served as an analytical framework for the study. The Watermaster model requires:

> "...three basic inputs: the spatial foundation of the Basin; the total supply of water at each point of diversion; and a list of all water rights that divert from stream flow, along with various characteristics of the rights." ... "The Watermaster then synthesizes the three inputs and allocates the available water through the queue of water rights. At each point of diversion, the program calculates the regulation date, the allocation of water (if any) to the water rights, and the stream flow that would result from this allocation." (Dole and Niemi 2004, 357)

Additional methods and technologies used in this case study included: monitoring data on natural stream flows, monitoring data on water releases from federal reservoirs in the basin, water rights data, amount of water diverted from the river under current conditions and with the three scenarios, amount used for in-stream flows, and water consumption from different types of uses. In effect, the study involved developing water balances for the WRB. The concepts and principles related to these tools are transferable to other river-basin studies. Also, mitigation and management considerations were imbedded in the analyses of the scenarios.

The general findings from this study were interesting. Specifically, Dole and Niemi (2004, 355) observed that:

> "...the results of our simulations were inconsistent with all of our expectations. We found that the web of interactions was not extensive, and that a basin-wide approach wasn't warranted. Increased urban demands had little impact on water allocation, but even an extensive application of the existing water conservation program was not sufficient to protect ecological values. As a result, we believe that protecting ecological values in the future will require sacrifices from more than water rights themselves, and involving society as a whole, in terms of not only the resources devoted to protecting the environment, but also the political will to make difficult changes."

7.3.6 Foundational study — use of indicators in assessing biological conditions of streams

The focus of this study was on the status of fish and aquatic invertebrate communities in all second-order to fourth-order streams in the WRB. The total length of these streams is 6,476 km. The study used five indicators of stream condition: fish IBI, native fish richness, WINOE (Willamette invertebrate observed/expected index), invertebrate EPT, and cutthroat trout abundance. Details on each of these indicators are in Van Sickle et al. (2004). Additional data were assembled for the stream network, riparian corridors, watersheds, stream reaches, and Strahler stream orders. Data were also aggregated for explanatory variables such as land use/land cover, physiography, and stream or river flows.

Regression models were developed for the relationships between the five indicators listed above and the three variables of physiography, land use/land cover, and streamflow. The latter two variables would be subject to change for the three 2050 scenarios. Model scenarios were developed by using sample data collected between 1993 and 1997 from 149 wadeable streams in the Basin (Van Sickle et al. 2004). Three areas of influence for land use/land cover were also examined: the entire watershed, a riparian corridor which is 120 m wide (on each side) of all upstream first-to-fourth order reaches, and a 30 m wide (on each side) local riparian corridor.

The development of the regression models provided the analytical framework for this study. Additional methods and technologies included land use/land cover and GIS, a whole-basin digital elevation model, the above-noted indicators, and US EPA sampling protocols. The concepts and principles of the regression models and indicators are transferable to other river basin studies. Mitigation and management issues are embedded in the analyses of the three scenarios.

The authors of this case study developed the following concluding remarks (Van Sickle et al. 2004, 368):

> "The projections show no significant change in basin-wide status in year 2050, relative to Circa 1990, for scenarios either of increased human development or continuation of current development trends, because landscape change under these scenarios is dominated by conversion of agricultural land to rural residential and urban uses, and because these changes affect only a small percentage of the Basin. However, under a

> scenario of increased conservation, regional medians of biotic status indicators are projected to improve by 9-24% by year 2050. None of the changes projected between Circa 1990 and year 2050 is as large in magnitude as the decline in status projected to have occurred between the time of pre-European settlement and Circa 1990."

7.4 Comparative discussion of case studies

Table 5 contains summary information derived from the six interrelated case studies. To provide for consistency in the comparisons, five topics are addressed as used within each case: (1) features, (2) environmental effects, (3) analytical framework(s), (4) methods and technologies, and (5) mitigation and management of changes. The comparative information displayed in Table 5 reveals the points listed below.

- The specific study features are unique for each of the five foundational studies.
- The addressed environmental effects within the five foundational studies are appropriate for examining experienced or potential effects from the studied causative changes in land use/land cover within the three 2050 scenarios.
- While the listed analytical frameworks are diverse, they each are scientifically defensible and consistent with similar types of studies.
- The identified methods and technologies are wide-ranging; however, they are pertinent for the causative and consequential changes and focus of each foundational study, and they are transferrable to other change-related studies. The types of tools routinely included land use/land cover information, GIS, selected indicators and indices, conceptual models, and simple-to-sophisticated mathematical models.
- The issues associated with mitigation and management were embedded in the analyses of the three 2050 scenarios.

Table 5. Comparative information on land uses and policy-related changes and their environmental and water resources consequences within the Willamette River Basin in Oregon.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Overview of Willamette River Basin study (Baker et al. 2004)	A comprehensive, basin-wide planning study of alternative futures (scenarios) to 2050 and how they will influence selected human use and natural resources indicators.	The broad categories include water availability, the Willamette River itself, ecological conditions of streams, and terrestrial wildlife; numerous indicators were utilized.	Key features are in Figure 8–they include trajectory of change, scenario development and scenario evaluation; stakeholder input was embedded in the study.	Mapping and GIS, indicators of human use and natural resources, various types of conceptual and mathematical models, calculations of percentage changes, and policy analyses; their concepts and principles would be transferable to other river basin studies	These considerations were embedded in the analyses of the three scenarios.
Foundational study – citizen guidance for scenario building (Hulse et al. 2004)	Incorporation of collaborative planning and citizen guidance into developing the three scenarios to 2050; specific attention devoted to conservation and restoration opportunities in the Conservation 2050 scenario.	Terrestrial habitats and vegetation, and opportunities for conservation and restoration	Logical and scientifically-defensible process which is in consonance with the state-of-practice for such studies.	Land use delineations and GIS mapping, collaborative planning, trends analyses and projections, and policy analyses; their concepts and principles would be transferable to other river basin studies.	Particular attention given to habitat conservation and restoration in the Conservation 2050 scenario.
Foundational study – evaluation of policy options on agricultural landscapes (Berger and Bolte 2004)	Identifying and evaluating physical changes associated with the three scenarios on agricultural land cover and use.	Farmland conversions, land uses associated with crop distribution, soil erosion, groundwater vulnerability, and wildlife habitat quality	Spatially explicit, multi-attribute, decision model and its required inputs	Agricultural landscape evolution model, agriculturally-related indicators, Universal Soil Loss Equation, groundwater vulnerability potential, and policy analyses; their concepts and principles would be transferable to other river basin studies	Embedded in the analyses of the three scenarios
Foundational study – wildlife responses to landscape and vegetation changes (Schumaker et al. 2004)	Basin-scale study of responses of 279 amphibian, reptile, bird, and mammal species to the three 2050 scenarios; findings would be useful for strategic planning.	Changes in habitat quantities and quality for species, and, as appropriate, changes in species populations	Simple model (PATCH) for species-habitat relationships, and a more complex model for selected species (SEPM)	Landsat imagery and GIS, PATCH, SEPM, literature reviews, and expert panels; concepts and principles would be transferable to other river basin studies.	Embedded in the analyses of the three scenarios

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
Water allocations and in-stream environmental flows (Dole and Niemi 2004)	Examination of the impacts of increased urban demand for water, and protection of ecological flows in Basin rivers and streams	River flows and user water rights	An Oregon water rights and water allocation model (called The Watermaster)	The Watermaster, monitoring data on river flows, releases from dams, diversions, and water consumption by different users	Embedded in the analyses of the three scenarios
Foundational study – use of indicators in assessing biological conditions of streams (Van Sickle et al. 2004)	Current and projected status of fish and aquatic invertebrate communities in second to fourth-order streams in the WRB	Changes in land use/land cover and stream flow variables and their consequential changes in five selected biological indicators (fish IBI, native fish richness, WINOE, invertebrate EPT, and cut throat trout abundance	Development of regression models to relate land use/land cover and stream flow variables to their consequences on the five biological indicators	Regression models, land use/land cover and GIS, sampling protocols, and selected monitoring programs; the concepts and principles of the regression models and indicators are transferable to other river basin studies	Embedded in the analyses of the three scenarios

7.5 Lessons learned

Based on this review of six interrelated case studies associated with land uses and policy-related changes and their effects on environmental and natural resources, the following lessons are noted.

- This comprehensive and well-funded set of case studies is not typical of river-basin planning efforts; however, information from one to all of them can be useful in planning such studies for other river basins. Further, the findings from these case studies have provided substantial contributions to the growing robust literature base for addressing physical changes from entire river basins and their consequences to runoff, streamflows, water use, water quality, and aquatic ecosystems.
- Regarding potential future causative and consequential changes, scenario analyses involving alternative futures can be a useful tool for bounding these issues.
- Mitigation and management of changes should be developed from a holistic perspective; that is, a range of options and their effectiveness should be considered, along with various combinations thereof. These case studies incorporated such considerations within the analyses of the three 2050 scenarios.

8 Physical, Social, and Institutional Changes Associated with Climate Variations and Climate Change

8.1 Introduction

This chapter summarizes three case studies related to PSI changes resulting from climate variations and climate change. Such changes can alter precipitation patterns, atmospheric temperatures, river flows, and aquatic ecology. Accordingly, water resources planning studies (including those for specific projects) should account for climate-related causative changes within river basins and their designated project or plan areas.

Section 8.2 presents the order of the three cases addressed in this chapter. In Section 8.3, Subsections 8.3.1–8.3.3 summarize information on each case derived from using the review form in Appendix A. Section 8.4 contains a comparative discussion of the key findings from each case. Finally, several overall lessons are highlighted in Section 8.5.

8.2 Order of case studies

The three case studies are presented in the order listed below.

1. Ice-related influences on fluvial geomorphology in a river (Ettema and Zabilansky 2004)
2. Flood risk management in an estuarine area (Bingley et al. 2008)
3. Climate-warming impacts on California water resources (Zhu et al. 2005).

These three case studies are presented within this report in an increasing order of complexity. The ice-related study is focused on consequential changes in fluvial geomorphology and aquatic ecosystem characteristics in the 190-mi. Fort Peck reach of the Missouri River (Ettema and Zabilansky 2004). The second case relates to natural land subsidence and increases in sea-level rise in the Thames River estuary in the United Kingdom. Emphasis is given to continued monitoring and evaluation of the physical changes and the development of flood defense structures to reduce risks in the estuary (Bingley et al. 2008). Finally, the PSI changes from 12 climate-

warming scenarios on central California water resources systems were examined by Zhu et al. (2005). This study also involved analyses of 73 years of historical records on rim inflows, groundwater inflows, local runoff, and evaporation from surface water reservoirs. Thus, it involved large geographical areas, long time periods (to 2100), and multiple alternative future scenarios.

8.3 Description of case studies

Following are summary descriptions of each of the three case studies. The common thread across all three cases involves PSI changes in climate and their environmental and water resources consequences.

8.3.1 Ice-related influences on fluvial geomorphology in a river

This case study relates to the influence of wintertime ice on stream channel morphology and stability in the Fort Peck reach of the Missouri River within Montana and North Dakota, comprising a distance of about 190 mi. (Ettema and Zabilansky 2004). Ice formation, presence, and breakup are typical annual occurrences in this northern portion of the United States. These causative changes (the ice and its movement) result from annual variations in wintertime weather. The consequential changes typically affect channel stability in the Fort Peck reach. For example, ice may hasten the migration of channel bends, cause transient scour and sediment deposition during the winter, and induce cyclic shifts of flow thalweg through sinuous-braided subreaches. These physical consequences can also disrupt aquatic ecological characteristics and habitat, including creating localized effects on aquatic life.

An important point to note is that there are annual variabilities in ice flows and their cumulative consequences over time. Further, from a geomorphological perspective, ice influences are often divided into hydraulic (river flow) influences and geotechnical influences. Combinations of these influences are of particular concern relative to effects on habitat, and they also need to be considered in project designs for areas which might be subject to ice and ice flows. Depending on the area's location, some mitigating designs might be considered.

This study did not include a specifically identified analytical framework; rather, the field monitoring and data collection were comprehensive and scientifically-based. More specifically, geomorphological monitoring tech-

niques and protocols were utilized. Further, these techniques and protocols, including visual surveys, are readily transferrable to other studies of ice-related changes.

8.3.2 Flood risk management in an estuarine area

The estuary region of the Thames River in the United Kingdom is subject to changes resulting from both natural land subsidence (also referred to as glacial isostatic adjustment) and anticipated future increases in sea level due to climate change (Bingley et al. 2008). This combination of changes in the study area is of concern in relation to long-term use of the estuary as well as minimization of local flood risks. The study included retrospective analyses (past few decades and past century) of geological information related to subsidence and historical sea level data from the study area. These studies revealed that causative changes to date have been minute; however, the issues could be exacerbated in future situations.

Accordingly, this study focused on retrospective analyses of data from a long-term, sophisticated, and complementary monitoring system. Specifically, global positioning system (GPS) and GIS, absolute gravimetric measurements, and persistent scatter interferometry have been and will continue to be used to determine locations and extent of land subsidence and of sea-level rises in the estuarine area. This information will aid in defining flood risks and in developing strategies to manage such risks.

To provide a perspective on the two types of changes, the geologically related changes range from about 0.3 mm/year uplift to 2.1 mm/year subsidence. When the sea-level-related changes are taken into account, the combined effects are expected to yield a 1.8–3.2 mm/year rise in sea level relative to the land along the Thames River estuary (Bingley et al. 2008). It is proposed that this sophisticated monitoring and analyses could form the basis for an adaptation strategy for long-term planning of infrastructure for flood and coastal defenses in the estuarine area.

Finally, the analytical framework involving long-term sophisticated monitoring and analyses is scientifically based and compatible with the current state of practice. This framework and the monitoring systems would have transferability to other coastal locations subjected to both land subsidence and sea-level rise.

8.3.3 Climate-warming impacts on California water resources

Based on a retrospective study (72 years, from October 1921–September 1993) of annual hydrologic conditions associated with California's entire and evolving, intertied, water system; this modeling study examined 12 future scenarios related to climate warming-induced changes and their cumulative influences on the system (Zhu et al. 2005). Some consequences of climate warming include changes in the seasonal distribution of runoff, with a greater proportion occurring during the wet winter months and less snowmelt runoff during the spring months. Spatial variations in these hydrologic changes would also occur.

Four hydrologic components of the water system were addressed in this study. The first, *rim inflows*, refers to major inflows into the Central Valley of the system from the surrounding mountains. The study addressed a total of 37 rim inflow sources. *Groundwater inflows* and *local runoff* were addressed by partitioning precipitation changes into local runoff and deep percolation portions for each groundwater sub-basin. These changes were then added to corresponding historical groundwater and local runoff time series. *Evaporation from surface water reservoirs* was the fourth hydrologic component. In total, these four components provide the basis for large-scale water balance calculations for the intertied state water system. Several indicators, mathematical models, regression models, and conceptual models were used for these calculations, and they are described by the authors (Zhu et al. 2005). The spatially disaggregated databases for these four components consisted of 131 streamflow, groundwater, and reservoir evaporation monthly time series for the 72-yr historical period.

The 12 climate-warming scenarios included various combinations of spatially averaged temperature increases ranging from 1.4–5.0 °C, and annual precipitation percentage increases ranging from 0%–62% (Zhu et al. 2005). The indicators and models as noted above were used to determine quantitative changes in the four hydrologic components as a result of each scenario. These water availability changes were then compared to projected changes in agricultural and urban water uses to the year 2100.

These findings provide a holistic perspective on potential alternative futures for California water resources. This information would be useful in planning adaptation strategies regarding the effects of climate change. Such strategies could include (a) reservoirs maintaining more empty space in order to provide current levels of flood protection from increased winter

storm runoff and (b) groundwater management involving conjunctive use and groundwater banking to meet increasing water demands under various climate-change scenarios.

Finally, transferability of methods and technologies is possible because this case study takes a broad approach to examining the effects of climate change on the hydrology of large areas, and it uses relatively simple methods to predict future changes under the 12 scenarios.

8.4 Comparative discussion of case studies

Table 6 contains summary information derived from the three case studies. To provide for consistency in the comparisons, five topics are addressed as used within each case: (1) features, (2) environmental effects, (3) analytical framework(s), (4) methods and technologies incorporated within the study, and (5) mitigation and management of changes. The comparative information displayed in Table 6 reveals the following points.

- The specific study features are unique for each case.
- The environmental effects addressed are appropriate for examining experienced or potential effects from the climate-related causative changes.
- While the listed analytical frameworks are diverse, they each are scientifically defensible and consistent with similar types of studies.
- The identified methods and technologies are wide-ranging; however, again they are pertinent for the causative and consequential changes and focus of each case. They are transferrable to other similar PSI change-related studies. The types of tools routinely included study-specific monitoring, GIS, indicators, and simple-to-sophisticated mathematical models.
- The three cases did not give major attention to mitigation and management; however, an inferred theme was the need for using composite strategies involving multiple components, design features, and management considerations.

8.5 Lessons learned

Based on this review of three case studies associated with climate-related changes and their effects on environmental and natural resources, the following lessons are noted.

- An expanding literature base is available for addressing climate-related changes and their consequences to runoff, stream flows and water quality, aquatic ecosystems, and groundwater systems.
- Retrospective analyses served as a useful foundation for these three cases. Regarding potential future causative changes and consequential changes, scenario analyses involving alternative futures can be a useful tool for bounding these issues (the Zhu et al. 2005 case utilized 12 climate-warming scenarios).
- Mitigation and management of climate-related changes and their consequences should be developed from a holistic perspective; that is, a range of design and management options and their effectiveness should be considered, along with various combinations thereof.

Table 6. Comparative information on climate-related changes and their environmental and water resources consequences.

Case Study	Summary of Information				
	Features	Environmental Effects	Analytical Framework	Methods and Technologies	Mitigation and Management of Changes
River ice-related influences on fluvial geomorphology in a river (Ettema and Zabilansky 2004)	Field monitoring and information collection on ice formation, movement, and break-up in the Fort Peck reach of the Missouri River; the consequential changes from ice are associated with channel stability and disruptions in aquatic ecosystems.	Physical changes on fluvial geomorphology (channel bends, scour, and sediment deposition) and on aquatic habitat and life	No specific framework was identified; however, the studies were scientifically based, comprehensive, and in keeping with professional practices.	Geomorphological monitoring techniques and visual surveys of the ice	Findings could be used for channel-related design features to minimize ice-related changes.
Flood risk management in an estuarine area (Bingley et al. 2008)	Monitoring and data analyses for long-term land subsidence and potential sea-level rises in the estuary of the Thames River in the United Kingdom	Geologically-related land subsidence and experienced and potential sea-level rises	The framework was associated with long-term monitoring of the two types of changes occurring in the study area; the approach is scientifically-based and indicative of the current state-of-practice	Use of global positioning system and GIS, absolute gravimetric measurements, and persistent scatter interferometry.	The study results could be used to develop long-term strategies for flood/risk defense structures in the estuarine zone.
Climate-warming impacts on California water resources (Zhu et al. 2005)	Examination of the consequential changes of 12 climate-warming scenarios on historical (72 yr) rim inflows, groundwater inflows, local runoff, and evaporation from surface water resources in California's intertied water system.	Spatial and quantitative effects of climate change on four hydrologic components within the water system.	Use of water balance calculations related to the four hydrologic components and future human and agricultural water uses	GIS, conceptual models, indicators, regression models, and mathematical models; concepts and principles would be transferrable to other water balance studies.	The study results could be used to develop multi-component management of water storage and use associated with surface water reservoirs and groundwater systems.

9 Summary

9.1 Methodology review

This report summarizes 31 case studies, primarily from peer-reviewed literature, where causative changes were connected to consequential changes associated with water resources planning and management. Consequential changes can also occur in runoff, water quality, and riparian and aquatic ecological features. A brief review of the chronology of PSI changes in planning practices and designs associated with the LP&VHPP and the flooding consequences of Hurricane Katrina is included in Chapter 2 to provide a situational context for this effort to review case studies which address PSI changes in major hurricane protection projects.

The 31 case studies were chosen from the initial identification of 580 documents, followed by a cursory review of 43 cases that met the study criteria. These chosen case studies then were subjected to systematic evaluation relative to their summary features as represented by causative changes. Additional reviews were focused on their consequential changes (environmental effects); use of analytical frameworks, and appropriate models, methods, and technologies; and the attention given to mitigation and/or management of the resultant types of changes.

For purposes of comparisons and relative evaluations, the 31 case studies were divided into six categories of causative changes associated with water resources planning. Chapters 3–8 contain the analyses and comparisons of the six categories of case studies. Tabulation of information and discussion of individual cases and their consequences revealed that each case exhibited unique features and focus; however, commonalities within and across the categories could be identified in relation to the use of frameworks and methods for analysis.

9.2 Observations

9.2.1 General observations of case studies

The general observations regarding the cases examined within each of the topical categories were:

- The study features were unique for each case.

- The consequential environmental effects addressed were logical for examining experienced or potential effects from the causative PSI changes.
- While the analytical frameworks used in the cases were diverse, they each provided a relevant structure for the included scientific and policy issues, land use and development project changes, and climate-change concerns.
- The identified methods and technologies were pertinent for addressing both the causative and consequential changes associated with each case.
- In general, only minimal direct attention was devoted to mitigation and management in the case studies; however, the causative PSI changes and effects findings resulting from each study could have been explored in detail in order to further address mitigation and management of the changes of concern.

9.2.2 Key observations for PSI changes

There are three key observations to the concept of PSI changes that are important in water resources management.

- The concept can be applied to all USACE mission areas.
- The planning process can be improved in a given watershed or sub-watershed by recognizing and understanding historic, current, and future changes in the identified study area. This action may require retrospective analyses to identify historic and current changes, and prospective analyses to designate potential future changes.
- Multiple projects, development, and policy decisions can be initiators of PSI changes.

9.3 Lessons learned

The key lessons derived from the reviews of the 31 cases included the following:

- They provide useful, "real-world" illustrations of the importance of addressing PSI changes in water resources planning and management. Further, they contain useful examples of analytical frameworks, models, methods, and technologies which have been used to address both causative and consequential changes.

- The large majority of the case studies did not actually incorporate the term “physical, social, and institutional changes.” This suggests that the specific term of PSI is relatively new and will take some time to become integrated within routine terminology used in water resources planning and management.
- Finally, it was not anticipated that such a large number of relevant case studies could be identified from the peer-reviewed literature. In addition, it can be surmised that the cases included are probably only a small sample of a much larger number of recent examples.

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Appendix A: Case Study Review Form

This Case Study Review Form (CSRF) as outlined below was used to review potentially useful case studies emphasized in peer-reviewed journal articles, conference papers, and specific research reports. A total of 43 documents related to potentially relevant case studies were identified. CSRF was developed to facilitate a consistent review by the authors of this report. A common review criteria (set of questions) was used, and each case study was categorized by types of PSI changes.

I. Citation (to be used in the cited references chapter of the final report).

II. Describe the extent to which each of the following considerations is discussed in this reference.

- What are the physical, social, and institutional changes that are discussed?
- Does the study help illustrate PSI changes or consideration of PSI changes?
- Is there an analytical framework for evaluating PSI changes?
- Is information on methods transferable to other efforts or studies?
- Is there discussion of mitigation and/or management of PSI changes?
- Is use of any tools discussed in the case study? Examples: GIS, indicators, scenarios, sustainability analysis, conceptual models, etc?
- Other factors?

III. Categorize this publication as one of the following:

- "Gem" — this reference is particularly useful in examining or demonstrating application of PSI changes.
- "Rock" — this reference has limited relevance in application of PSI changes.
- "Yawner" — this reference has little or no usefulness in examining PSI changes.

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14. ABSTRACT

The US Army Corps of Engineers is increasingly moving toward a watershed or systems-based approach to water resources management infrastructure. A key component of this holistic approach is understanding the current context of the watershed and the many changes that have shaped the existing system. This report summarizes and compares 31 case studies where causative physical, social, and institutional (PSI) changes were connected to consequential PSI changes associated with water resources planning and management. Consequential changes can also occur in runoff, water quality, and riparian and aquatic ecological features. The 31 studied cases were systematically evaluated relative to: causative and consequential PSI changes (environmental effects); use of analytical frameworks and appropriate models, methods, and technologies; and the attention given to mitigation and/or management of the resultant changes. Some general observations and lessons learned were that study features were unique for each case; consequential environmental effects appeared to be logical, based on the causative changes; analytical frameworks provided a relevant structure for studies; and identified methods and technologies were pertinent for addressing both causative and consequential changes. One key lesson derived from the case study reviews was that they provide useful, "real-world" illustrations of the importance of addressing PSI changes in water resources planning and management.

15. SUBJECT TERMS
watershed management, infrastructure, water resources, case studies, evaluation, PSI changes

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